401469

# VOLUME 1

# REPORT

# GROUND-WATER HYDROLOGY CHARACTERIZATION

# FRENCH GULCH MINE POOL

# BRECKENRIDGE, COLORADO

April 1995

Prepared for:

U.S. Environmental Protection Agency
Region VIII

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# ACKNOWLEDGEMENTS

I would like to thank Al Dreher (Mobil Oil Corporation) and Mark Arnold (American Geologic Services, Inc) for their contributions to the aquifer testing. Their technical assistance and supplying of equipment made these tests possible. I would especially like to credit Al Dreher for his time and effort in running the aquifer modelling software which was made available through Mobil Oil. Bill Stone (BST Graphics) was responsible for drafting the figures in this report and supplying overheads slides. I would also like to thank Snyder Oil Corporation for allowing me to used their Geographic Information System. The French Gulch technical team which consisted of Bruce Stover (Colorado Division of Minerals and Geology) and Orville Kiehn and Michael Wireman from the U.S. Environmental Protection Agency provided assistance and were instrumental in implementing the work accomplished in this study.

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# *GROUND-WATER HYDROLOGY CHARACTERIZATION FRENCH GULCH MINE POOL*

## Executive Summary

The French Gulch Nonpoint Source (NPS) Project was initiated in 1990 by the State of Colorado. The purpose of this project was to address nonpoint source discharges from the Wellington-Oro (W-O) mine and mill site into French Creek. This ground-water hydrology study was jointly conducted with the Colorado Division of Minerals and Geology and the U.S. Environmental Protection Agency Region VIII Water Management Division.

The study area is located two miles east of Breckenridge, Colorado. Extensive placer and underground lode mining occurred along French Gulch from the late 1850's to the 1960's. The W-O mine produced large quantities of zinc, lead, silver, and gold, and minor amounts of copper. The ore was extracted through an extensive network of tunnels and adits. A large portion of the mine workings are below the elevation of French Creek and the ground-water table. Several levels are presently flooded (SAIC, 1993 & Stover, 1994). The Wellington-Oro mill processed ore from 1908 to the 1950's. It has been estimated that 32,000 cubic yards of mill tailings and 13,000 cubic yards of roaster fines remain on the site (Stover, 1994).

Surface and ground-water sampling have demonstrated heavy metal loadings from the W-O site into French Gulch. Metals are the primary cause of poor water quality and lack of trout populations in French Creek and reduced trout populations in the Blue River immediately below the confluence with French Creek (SAIC, 1993 & Stover, 1994). Origins of the French Creek heavy metals pollution include surface and ground-water sources. Surface sources consist of mill tailings discarded into French Gulch, "roaster fines" at the mill site, and mine waste rock. Ground-water contamination sources are associated with drainage from the flooded underground mine workings and seepage of leachate from surface tailings and mine waste piles. This study focused on characterizing the ground-water transport of metals to French Creek. The ability to characterize, understand, and isolate sources of contamination will be very useful for any future surface and underground remediation activities.

There are two hydrostratigraphic units in the vicinity of the W-O site; an alluvial aquifer, and the underlying fractured shale bedrock. The mine workings are associated with the fractured shale and Tertiary intrusives that cut the shale. Aquifer tests were conducted on the alluvium and shale for the purpose of characterizing ground-water flow between the two aquifers. Ground-water chemistry and geologic data were also integrated to evaluate the hydraulic communication between aquifers and to assess the extent of ground-water transport of metals to French Creek. This study will serve as a pilot approach for the U.S. Environmental Protection Agency and the State of Colorado on characterization of metal loadings to streams from ground-water sources at inactive mine sites. In addition, results from this study can be applied to designing and implementing ground-water tracer surveys and selecting remediation techniques at French Gulch.

The aquifer tests, ground-water chemistry, and geology indicated that the W-O mine workings, the fractured shale bedrock, and the alluvial aquifer are in hydraulic communication. Drawdown was observed in all monitoring wells during the alluvium and shale constant discharge tests. Drawdown versus time curves were modelled with the computer software package AQTESOLV (Geraghty & Miller, 1989). The best curve matching of drawdown curves for the alluvial and shale aquifers occurred with leaky semi-confined aquifer solutions (Hantush and Jacob, 1955 & Hantush, 1960). Results from the slug and constant discharge tests for the alluvial aquifer indicated horizontal hydraulic conductivities of 20 to 65 ft/day which are typical for sand and gravel (Kruiseman & DeRidder, 1989). The shale aquifer horizontal hydraulic conductivities ranged from 1.8 to 6 feet per day. These conductivities are very high for typical shale values and are probably due to fracturing (Kruiseman & DeRidder, 1989). The shale vertical hydraulic conductivities were estimated at 0.03 to 0.84 feet per day which are also very high for typical shale values.

The shale and alluvium ground-water chemistry were similar with both waters having dominant calcium-magnesium cation facies and an extremely dominant sulfate anion facies. The mapping of ground-water chemical parameters and metal concentrations showed that the major source of metals pollution is in the area of the mine and mill site with the fractured shale containing the most polluted waters. Metal polluted ground-water in the vicinity of the W-O mine and mill site are chemically very similar to down valley seeps that flow into French Creek. High iron concentrations were observed with low cadmium, zinc, and other metal concentrations in the alluvium ground-water associated with French Gulch. This may be due to the oxidation of iron sulfides. The oxidation process can absorb other metals from the ground waters and form precipitates (Manahan, 1991).

Warmer alluvium ground-water temperatures were observed in the vicinity of the mine and mill site. This suggests that at some time there has been an upward vertical gradient and influx from deeper ground-water. The static water levels in the area of the constant discharge pump tests and the W-O mine and mill site indicated that the fractured shale bedrock may be acting as a sink for the mine and alluvial waters. Potentiometric surface mapping showed significant ground-water flow from the W-O mine and mill site into French Gulch with very high hydraulic gradients of 0.05 to 0.1. It is estimated that the average linear velocity for the alluvium ground-water range from 3 to 22 feet per day and the shale ground waters range from 2 to 12 feet per day.

This study concluded that significant metals loading into French Creek occurs from the shale bedrock and the metals are transported via ground-water pathways to French Creek. The relative contribution of surface leaching of metals from the mine waste rock, roaster fines, and mill tailings and metals from the mine waters to the ground-water needs further investigation. The following recommendations will assist in answering many questions addressed in this study:

(1) monitor static water levels in the ground-water wells to determine seasonal changes in vertical and horizontal ground-water movement;

(2) install stage recorders in the mine pool and French Creek;

(3) drill additional shale monitoring wells in the vicinity of alluvial well #7 and the W-O mine site,

(4) drill an alluvial monitoring well south of French Creek near the Country Boy Mine road;

(5) compare the shale water chemistries with the alluvial, mine, and seep waters;

(6) conduct geophysical surveys on the new wells to evaluate vertical ground-water movement;

(7) investigate tracer surveys that would incorporate the shale wells, alluvial wells, mine workings, and the down valley seeps;

(8) conduct leaching tests on the mill tailings, roaster fines, and mine waste rock to determine their potential for metal loading;

(9) re-design the surface water sampling surveys

incorporating the results of this study;

(10) evaluate the surface and ground-water chemistry in terms of metal speciation, complexation, solubilities, redox reactions, ion exchange, and other possible aquatic reactions; and

(11) compile all available underground mine maps for volumetric, metal loading, and mass balance analyses.

# GROUND-WATER HYDROLOGY CHARACTERIZATION FRENCH GULCH MINE POOL

## INTRODUCTION

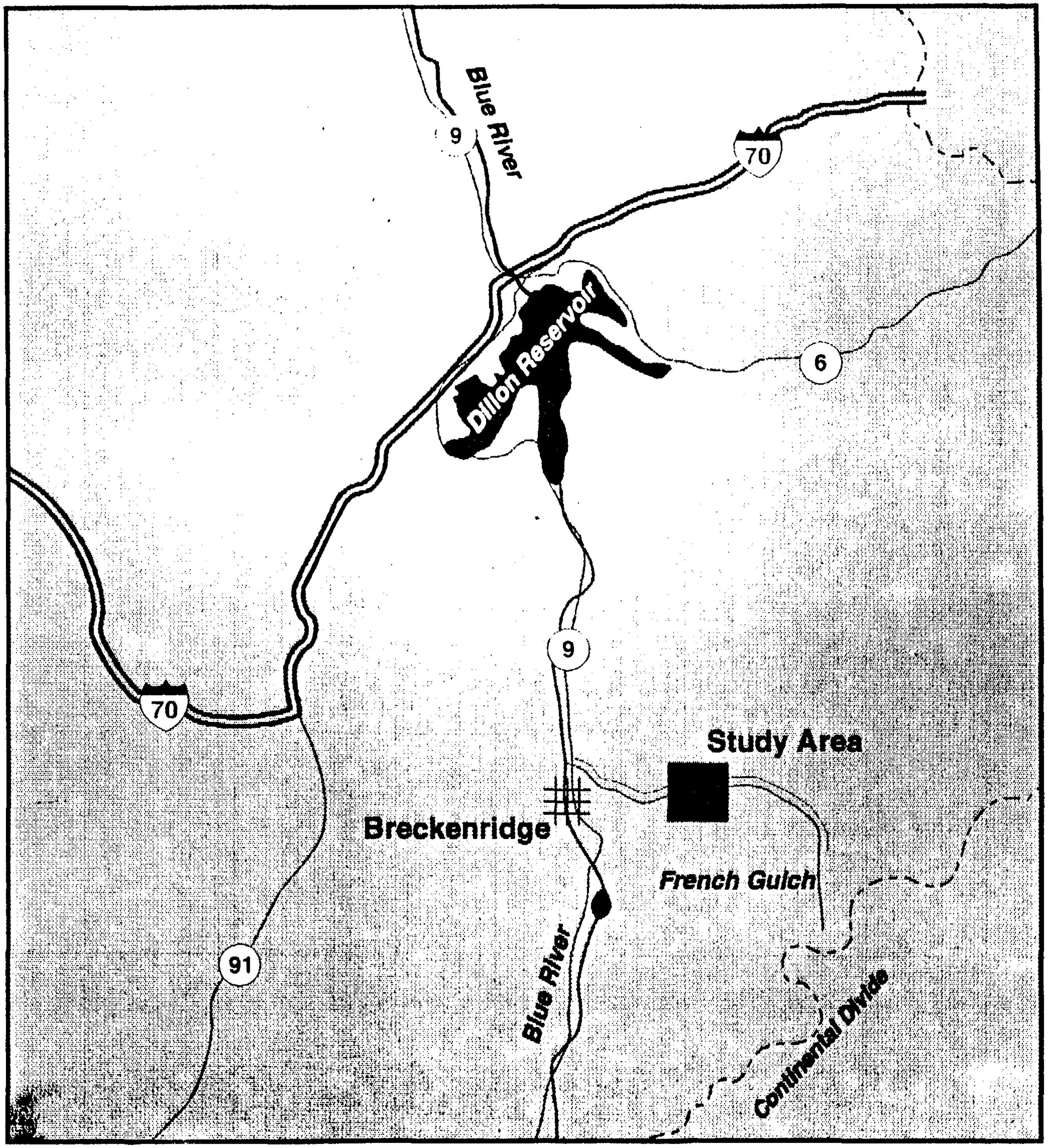
### Background

This study was jointly conducted with the Colorado Division of Minerals and Geology (DMG) and the U.S. Environmental Protection Agency (EPA) Region VIII Water Management Division during the second half of 1994. The French Gulch Nonpoint Source (NPS) Project was initiated in 1990. The purpose of the French Gulch NPS Project was to address nonpoint source discharges from the Wellington-Oro (W-O) mine and mill site into French Creek. NPS programs are authorized by Section 319 of the Federal Clean Water Act. The U.S. Environmental Protection Agency (EPA) administers Section 319 NPS provisions by providing grant funds to State agencies. The Colorado Department of Health's Water Quality Control Division (CDH) is the responsible agency for administrating Colorado's nonpoint source program. Colorado's Division of Minerals and Geology (DMG) has been designated as the "operating agency" for the French Gulch NPS Project (SAIC, 1993). The EPA also provides technical assistance to DMG.

## Description of Study Area

French Creek originates along the Continental Divide in Summit County and flows north and west for over six miles to its confluence with the Blue River near the town of Breckenridge, Colorado (Figure 1). The Blue River flows into the Dillon Reservoir approximately ten miles north of Breckenridge. The Wellingtion-Oro (W-O) site is located in the valley of French Gulch about two miles upstream (east) of Breckenridge. Extensive placer and underground lode mining occurred in this glaciated high mountain valley from the late 1850's to the 1960's. Lode mining was concentrated on the fairly steep valley sides where lead-zinc-silver sulfide ores and rich gold ores were found in veins associated with partially metamorphosed Cretaceous sediments and intrusive Tertiary quartz monzonite porphyry bodies. Large floating dredge boats were used to placer mine the valley floor for gold from glacial outwash and stream gravel deposits (Stover, 1994).

There are several abandoned mine sites in the valley. The W-O mine site is the largest and it is believed to be the greatest source of heavy metals to French Creek (Stover, 1994). The W-O mine produced large quantities of zinc, lead, silver, and gold, and minor amounts of copper from the early 1880's to the 1950's (SAIC, 1993). Zinc was commonly discarded with the tailings during early




# Location Map

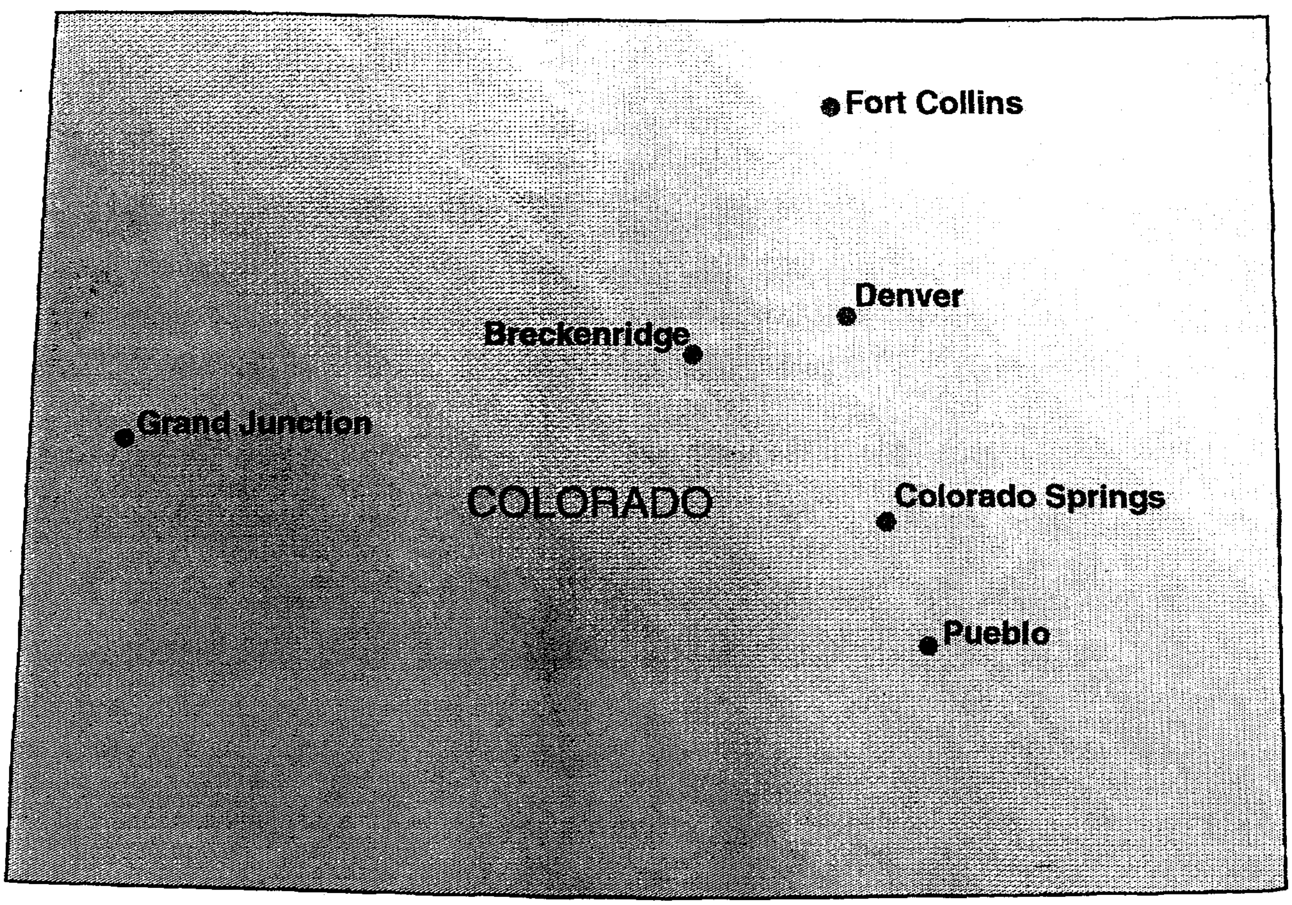
N

Kilometers
0 8

0 5
Miles

FIGURE 1

LOCATION MAP OF STUDY AREA



operations of the mine. Local smelters would not process zinc in the late 1800's. Cadmium and other metals were also discarded throughout the mine and mill operations. The ore was extracted through an extensive network of tunnels and adits. This network consisted of at least eighteen levels. More than six of these tunnels and adits are below the elevation of French Creek and the ground-water table. Mining was discontinued in the 1950's due to the prohibitive expense associated with pumping water from the underground mine. A significant portion of the mine is presently flooded (SAIC, 1993). The flooded portion represents over 80% of the mine workings. A mill was located on the W-O site to process ores from 1908 until the 1950's when mining at the W-O site ceased. It has been estimated that 32,000 cubic yards of mill tailings and 13,000 cubic yards of roaster fines remain on the site (Stover, 1994).

Excessive concentrations of cadmium, copper, iron, lead, zinc and other metals occur in the ground-water underneath the W-O site (Table I). These metals have been detected in French Creek and the Blue River (Figure 2, Table II). Zinc and cadmium toxicity have eliminated trout populations from the lower two miles of French Creek and have caused reduced trout populations in the Blue River three miles downstream from the confluence with French Gulch (Stover, 1994). French Creek meets the class 1 cold water aquatic life stream classification standard above the W-O site. Below the

# Table I Ground-Water Chemistry

| ALLUVIAL GROUND-WATER QUALITY DATA FROM JUNE AND AUGUST, 1991: TOTAL METALS (μg/l)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Metal | Well Number | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Aluminum | 2600/3300 | 95 | N/A | 33000/84 | 11000/490 | 75000 | 17000/4300 | 260,000/ < 50 |
| Cadmium | 160/120 | 0 9 | 94/57 | 53/42 | 71/78 | 230 | 24/4.2 | 220/180 |
| Copper | 71/69 | < 4 | 47/19 | 270/10 | 100/68 | 660 | 150/120 | 340/ < 4 |
| Iron | 85000/53000 | 74000 | 190000/200000 | 120000/86000 | 100000/65000 | 270000 | 57000/30000 | 2300000/77000 |
| Lead | 560/1000 | < 5 | < 20/340 | 1000/50 | 320/70 | 6700 | 700/600 | 1700/190 |
| Manganese | 31000/25000 | 26000 | N/A | 36000/32000 | 31000/34000 | 62000 | 9100/130000 | 88000/37000 |
| Nickel | 110/100 | 100 | N/A | 210/160 | 140/160 | 300 | 27/ < 40 | 360/130 |
| Selenium | 27/26 | 26 | N/A | 25/23 | 25/22 | 38 | 26/16 | 60/36 |
| Silver | 1.2/2.0 | 0 3 | N/A | 1.7/0.3 | 0.9/20 | 20.0 | 4.0/2.0 | 8.3/0.3 |
| Zinc | 110000/94000 | 43000 | 120000/110000 | 140000/120000 | 110000/120000 | 200000 | 18000/8800 | 570000/140000 |

## Table I (continued)

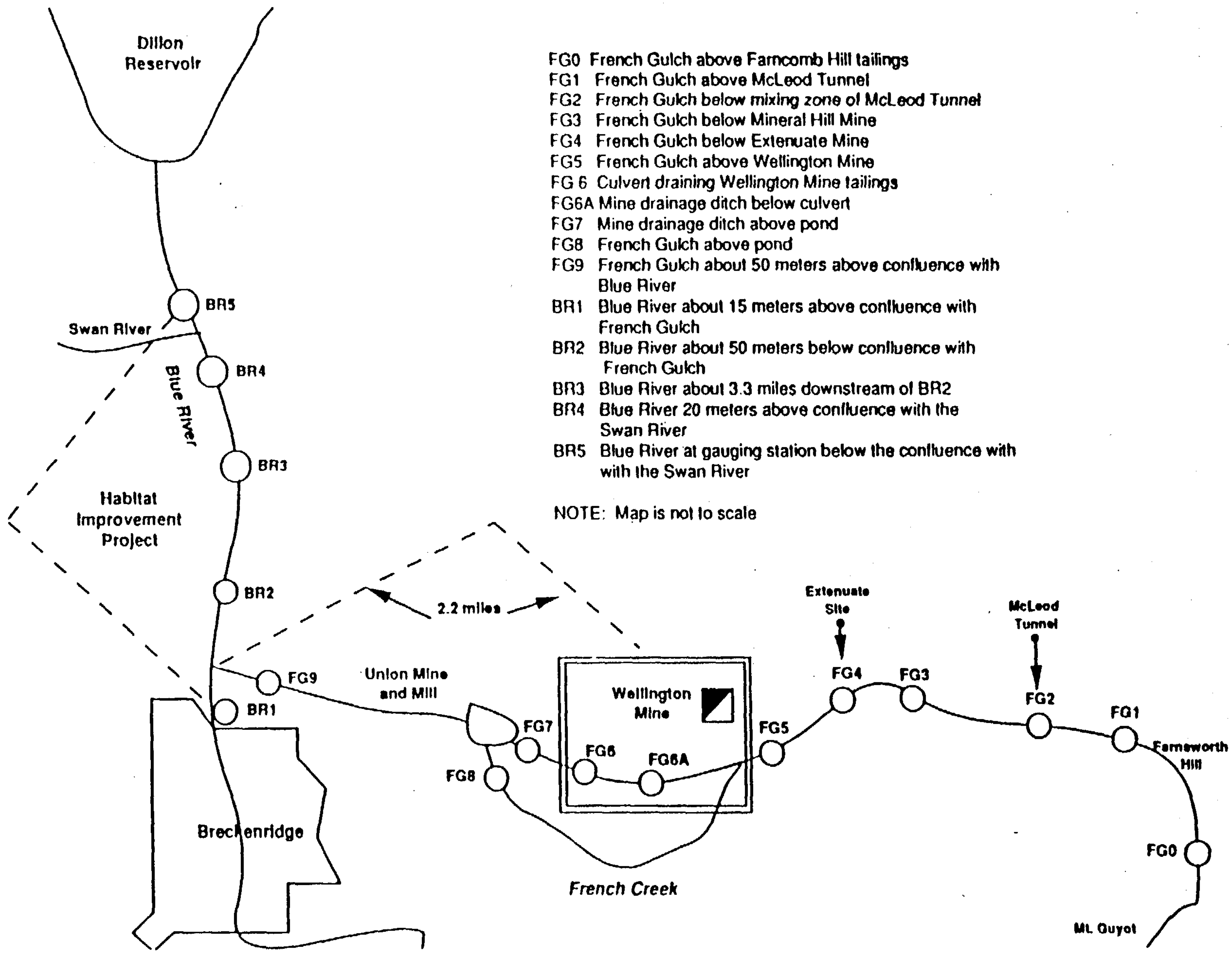
| GROUNDWATER QUALITY DATA FROM NOVEMBER 1993: TOTAL METALS, ((µg/l)* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Well No. | Aluminum | Cadmium | Copper | Iron | Lead | Manganese | Nickel | Silver | Zinc |
| 1 | N/A | 54.6 | 12.7 | 94,910 | 290 | 33,120 | N/A | <0.3 | 125,300 |
| 2 | N/A | 2 9 | 1.6 | 157,800 | 2.5 | 28,990 | N/A | <0.3 | 73380 |
| 3 | N/A | 26.0 | 0.6 | 246,100 | 139 | 41,160 | N/A | <0.3 | 133,100 |
| 4 | N/A | 36.2 | 2.5 | 80,110 | 33.2 | 31,900 | N/A | <0.3 | 121,900 |
| 5 | N/A | 61 3 | 3.5 | 99,360 | 20.9 | 35,990 | N/A | <0.3 | 127,900 |
| 6 | N/A | 6.3 | 1.3 | 56,700 | 15.6 | 21,670 | N/A | <0.3 | 47,980 |
| 7 | <40 | 1 1 | 1.8 | 50,400 | 3.3 | 15,600 | <15 | <0.3 | 21,360 |
| 8L | N/A | 197 | 2.2 | 105,500 | 66.1 | 45,250 | N/A | <0.3 | 190,900 |
| 8U | 39,800 | 484 | 137 | 541,800 | 1,107 | 51,940 | N/A | 1.0 | 262,900 |
| 9 | 110 | 1.8 | 2 8 | 436 | 6.1 | 32 | <15 | <0.3 | 129 |
| 11 | 308 | 24 8 | 6 4 | 276. | 36.7 | 78 | <15 | <0.3 | 2,977 |
| 12 | 10,250 | 11.3 | 34.4 | 18,490 | 47.4 | 1,531 | <15 | <0.3 | 2,082 |
| 13 | N/A | 3,650 | 154 | 46,200 | 685 | 130,200 | 1,078 | 0.7 | 1,448,000 |
| 14 | 185 | <0.5 | 2.1 | 116 | 1.1 | 493 | <15 | <0.3 | 64 |

* Samples were obtained at one depth for all wells except #8. Depths on wells 1, 3, 4, 5, and 7 were not designated (i.e., data are not directly comparable to Table 3A).

from SAIC (1994)

FIGURE 2

MAP
OF
FRENCH CREEK AND BLUE RIVER
WATER SAMPLE LOCATIONS




from SAIC (1994)

# Table II French Creek and Blue River Chemistry

FRENCH GULCH NONPOINT SOURCE STUDY: MAY 1989, SEPTEMBER 1989, SEPTEMBER 1990 AND SEPTEMBER 1992, OCTOBER 1993, AND NOVEMBER 1993 (μg/l) (continued)

| Sample Site | Date | pH | Cadmium (T/D) | Copper (T/D) | Iron (T/D) | Lead (T/D) | Ag (T/D) | Mn (T/D) | Zinc (T/D) |
|---|---|---|---|---|---|---|---|---|---|
| French Gulch Water Quality Standards | | 6.5-9.0 | 2.2:4 | 17.8:11.8 | 1,000:None | None | N/A:.1 | 1,000:None | N/A:1,980 |
| FG9 | 5/89 | 6.85 | 8.2/7.1 | BD/BD | 330/NS | 6/BD | BD/BD | 740/NS | 4400/4500 |
| | 9/89 | 5.84 | 4.3/4.3 | BD/BD | 140/NS | BD/BD | BD/BD | 460/NS | 1900/1900 |
| | 9/92 | 7.91 | 5.9/6 | 1.3/< 1 | 164/< 10 | 7.8/< 3 | < 1/< 1 | 355/361 | 1923/1830 |
| | 10/93 | 7.80 | 6.8/6.6 | < 1/< 1 | 105/14 | 9.0/1.4 | < 0.3/< 0.3 | 413/460 | 2605/2872 |
| | 11/93 | 7.75 | 8.4/7.4 | 1.6/< 1 | 171/< 5 | 8.6/1.6 | < 0.3/< 0.3 | 538/524 | 3411/3337 |

Key: Standard Standard - Acute.Chronic; NS - Not Sampled; T - Total; D - Dissolved; BD - Below detection limits; N/A - No Standard
[1] The May 1989 FGD4 sample collected directly from mine waste pile runoff. Other FGD4 values represent samples collected from the French Creek at the Extenuate site.

FRENCH GULCH NONPOINT SOURCE STUDY: MAY 1989, SEPTEMBER 1989, SEPTEMBER 1990, SEPTEMBER 1992, OCTOBER 1993, AND NOVEMBER 1993 (μg/l) (continued)

| Sample Site | Date | pH | Cadmium (T/D) | Copper (T/D) | Iron (T/D) | Lead (T/D) | Ag (T/D) | Mn (T/D) | Zinc (T/D) |
|---|---|---|---|---|---|---|---|---|---|
| Blue River WQ Standards | | 6.5-9.0 | 2.2:1.1 | 17.8:11.8 | 1,000:None | 95.8:3.89 | 2.0:0.075 | 1,000:None | 218:45 |
| BR1 | 5/89 | 7.51 | .44/.30 | 6/7 | 770/NS | 8/BD | BD/BD | BD/NS | 110/60 |
| | 9/89 | 6.41 | BD/BD | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 10/BD |
| | 9/90 | NS | NS/BD | NS/5 | NS/BD | NS/BD | NS/BD | NS/BD | NS/BD |
| | 9/92 | 8.36 | < 0.5/< 0.5 | 1.8/< 1 | 164/< 10 | 3.7/< 3 | < 1/< 1 | 17/5 | 0.224/0.072 |
| | 10/93 | 7.98 | < 0.5/< 0/5 | < 1/< 1 | 65/18 | < 1/< 1 | < 0.3/< 0.3 | 4.0/2.0 | 29/22 |

## Table II (continued)

| FRENCH GULCH NONPOINT SOURCE STUDY: MAY 1989, SEPTEMBER 1989, SEPTEMBER 1990 AND SEPTEMBER 1992, OCTOBER 1993, AND NOVEMBER 1993 (μg/l) (continued) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample Site | Date | pH | Cadmium (T/D) | Copper (T/D) | Iron (T/D) | Lead (T/D) | Ag (T/D) | Mn (T/D) | Zinc (T/D) |
| French Gulch Water Quality Standards | | 6.5-9.0 | 2.2:4 | 17.8:11.8 | 1,000:None | None | N/A:.1 | 1,000:None | N/A:1,980 |
| FG5 | 5/89 | 7.42 | BD/BD | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 20/10 |
| | 9/92 | 6 83 | 0 6/<0 5 | 1.1/<1 | 52/<10 | <3/<3 | <1/<1 | 12/2 | 115/84 |
| | 10/93 | 7 99 | <0.5/<0.5 | <1/<1 | 83/15 | 1.0/<1 | <0.3/<0.3 | 17/3.0 | 67/27 |
| | 11/93 | 7 88 | <0.5/<0.5 | 1.9/<1 | 62/37 | <1/<1 | <0.3/<0.3 | 18/22 | 80/109 |
| FG6 | 5/89 | 4.37 | 61/NS | BD/NS | 3700/NS | 270/NS | .34/NS | 4900/NS | 17000/NS |
| FG6A | 5/89 | 6.33 | 29/25 | 22/11 | 28000/NS | 82/BD | .33/.30 | 17000/NS | 51000/49000 |
| | 9/89 | 5.23 | 31/43 | 6/BD | 66000/NS | 33/BD | BD/BD | 26000/NS | 66000/7000 |
| | 9/92 | 6.03 | 15/14.9 | <1/<1 | 41080/38540 | 56.7/3.6 | 1.7/2.9 | 15690/15720 | 43360/41260 |
| | 10/93 | 6 73 | 25.6/24 | 6.0/6 0 | 62091/62570 | 72.1/3.3 | <0.3/<0.3 | 24900/26040 | 69000/69550 |
| | 11/93 | 6.67 | 25.0/21.6 | 4.2/<6 | 60620/58400 | 73/6.0 | <0.3/<0.3 | 24080/23500 | 64930/60400 |
| FG7 | 5/89 | 6.90 | 12/12 | BD/BD | 1200/NS | 5/BD | BD/BD | 3900/NS | 14000/9300 |
| | 9/92 | 6.54 | 6.7/6.3 | <1/<1 | 302/27 | <3/<3 | <1/<1 | 699/698 | 3000/2827 |
| | 10/93 | 7 92 | 7.9/7.4 | <1/<1 | 282/10 | 1.9/<1 | <0.3/<0.3 | 729/767 | 3193/3254 |
| | 11/93 | 7 80 | 9.7/9.5 | <1/<1 | 296/56 | 2.6/<1 | <0 3/<0.3 | 852/860 | 4183/4198 |
| FG8 | 5/89 | 7 18 | 2/1 8 | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 660/650 |
| | 9/89 | 6.17 | 2/1 9 | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 470/460 |
| | 9/92 | 6 69 | 4.9/4.6 | 1 6/<1 | 113/30 | <3/<3 | <1/<1 | 218/224 | 1547/1516 |
| | 10/93 | 7.31 | 3.0/7.5 | <1/<1 | 43/21 | <1/9 | <0.3/<0.3 | 83/88 | 749/792 |
| | 11/93 | 7 29 | 4.6/4.6 | <1/<1 | 27/<5 | <1/<1 | <0 3/<0.3 | 141/143 | 1453/1479 |

Table II (continued)

| FRENCH GULCH NONPOINT SOURCE STUDY: MAY 1989, SEPTEMBER 1989, SEPTEMBER 1990, SEPTEMBER 1992, OCTOBER 1993, AND NOVEMBER 1993 (µg/l) (continued) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample Site | Date | pH | Cadmium (T/D) | Copper (T/D) | Iron (T/D) | Lead (T/D) | Ag (T/D) | Mn (T/D) | Zinc (T/D) |
| Blue River WQ Standards | | 6.5-9.0 | 2.2:1.1 | 17.8:11.8 | 1,000:None | 95.8:3.89 | 2.0:0.075 | 1,000:None | 218:45 |
| | 11/93 | 7.84 | 0.6/<0.5 | 1.1/<1 | 147/11 | 1.0/<1 | <0.3/<0.3 | 8.0/2.0 | 35/23 |
| BR2 | 5/89 | 6.90 | 6/6 | BD/BD | 280/NS | 5/BD | BD/BD | 710/NS | 4300/4200 |
| | 9/89 | 6.10 | 4.4/4.3 | BD/BD | 140/NS | BD/BD | BD/BD | 520/NS | 2200/1700 |
| | 9/90 | NS | NS/4.8 | NS/BD | NS/BD | NS/BD | NS/BD | NS/530 | NS/2000 |
| | 9/92 | 7.98 | 5.5/5.1 | 1.3/<1 | 164/<10 | 5.5/<3 | <1/<1 | 365/368 | 1993/1887 |
| | 10/93 | 7.85 | 6.9/6.7 | <1/1.0 | 119/14 | 9.7/1.8 | <0.3/<0.3 | 452/496 | 2821/3077 |
| | 11/93 | 7.71 | 7.2/6.8 | <1/<1 | 127/34 | 10.4/1.9 | <0.3/<0.3 | 366/<1 | 2931/2946 |
| BR3 | 5/89 | 7.46 | .40/.40 | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 70/80 |
| | 9/89 | 6.64 | 0.5/0.4 | BD/BD | BD/NS | BD/BD | BD/BD | BD/NS | 70/50 |
| | 9/90 | NS | NS/4.3 | NS/BD | NS/BD | NS/BD | NS/BD | NS/480 | NS/1900 |
| | 10/93 | 8.18 | <0.5/<0.5 | <1/<1 | 148/22 | 3.2/<1 | <0.3/<0.3 | 10/3.0 | 83/71 |
| | 11/93 | 8.13 | 0.6/<0.5 | 1.7/<1 | 248/127 | 2.2/<1 | <0.3/<0.3 | 10/<1 | 83/60 |
| BR4 | 9/90 | NS | NS/2.2 | NS/BD | NS/BD | NS/BD | NS/BD | NS/BD | NS/630 |
| | 9/92 | 8.30 | 0.8/<0.5 | 1.7/<1 | 45/<10 | 3.6/<3 | <1/<1 | 6/3 | 74/53 |
| BR5 | 9/90 | NS | NS/0.3 | NS/BD | NS/BD | NS/BD | NS/BD | NS/BD | NS/190 |
| | 9/92 | 8.32 | <0.5/<0.5 | <1/<1 | 46/<10 | 3.8/<3 | <1/<1 | 5/3 | 44/31 |

Key: Standard:Standard - Acute:Chronic; NS - Not Sampled; T - Total; D - Dissolved; BD - Below detection limits; N/A - No Standard
[1] The May 1989 FGD4 sample collected directly from mine waste pile runoff. Other FGD4 values represent samples collected from the French Creek at the Extenuate site.

from SAIC (1994)

W-O site French Gulch does not meet either class 1 or the class 2 recreation designation. Metal pollution from French Gulch results in zinc and cadmium concentrations in the Blue River, below its confluence with French Gulch, exceeding the Colorado Department of Health's chronic toxicity values for trout (Tables II & III) by 38 to 93 times for zinc and 3 to 4 times for cadmium (Stover, 1994).

**TABLE III**

**CHRONIC TOXICITY VALUES[1] FOR RAINBOW, BROWN, AND BROOK TROUT**

| METAL | RAINBOW | BROWN | BROOK |
|---|---|---|---|
| Cadmium | unk. | 2.0[2] | 1.7-3.4 |
| Zinc | 47.0 | 225.0 | 532.0-1368.0 |

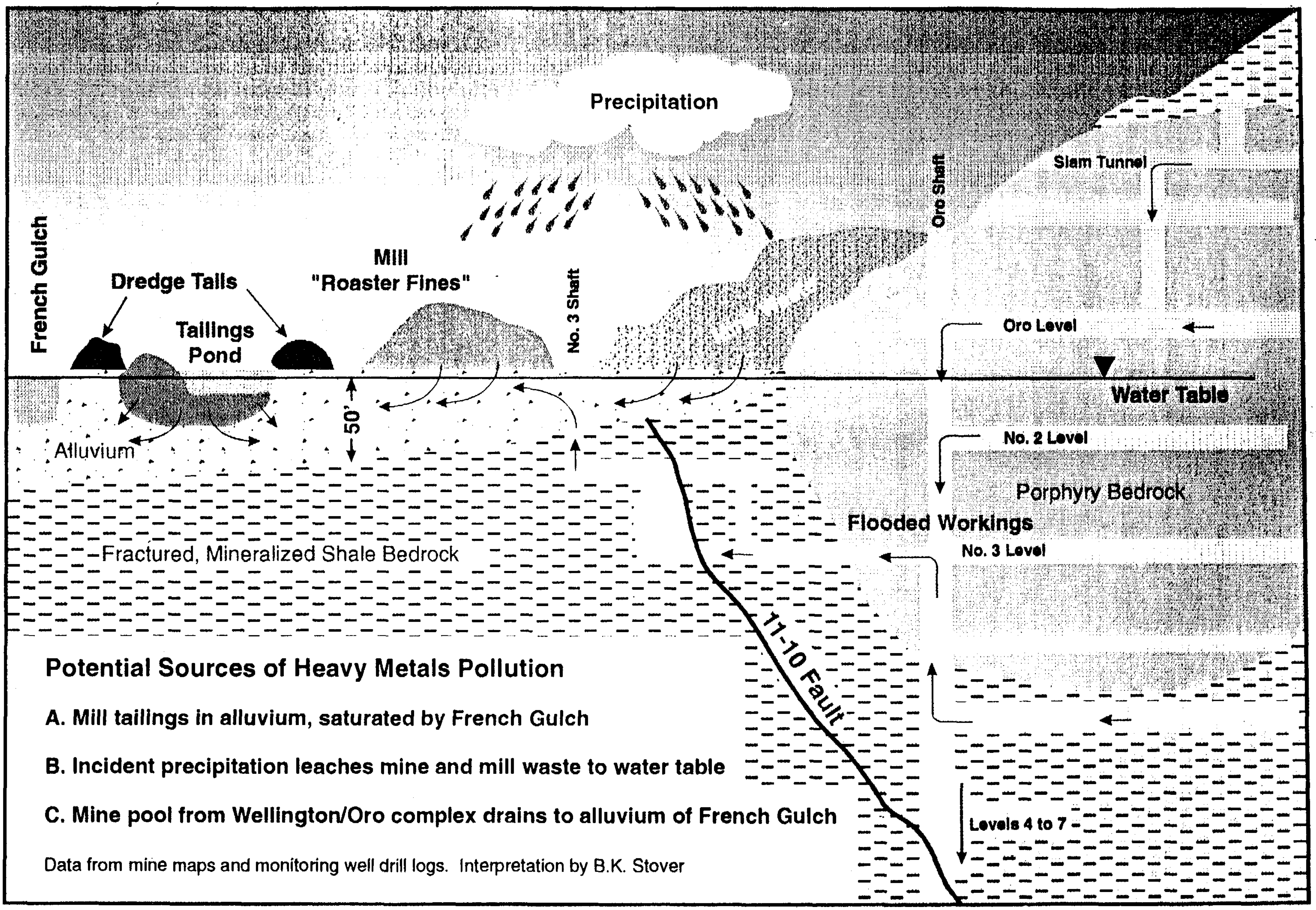
[1] Metal concentration in ug/l
[2] Acclimated trout
unk. unknown concentration
after: Lehnertz, 1989. Draft Clear Creek Basin 1989 Report

These waters flow into the Dillon Reservoir which is a municipal water supply for the Denver Metro Area (Stover, 1994).

Possible sources of the French Creek heavy metals pollution from the W-O site include both surface water and ground water (Figure 3). Surface contamination includes direct runoff of leachate from surface tailings and leaching of metals from tailings that were discarded directly into French Gulch. Ground-water contamination sources include drainage from flooded underground mine workings and seepage of leachate from surface tailings which

FIGURE 3
SCHEMATIC CROSS SECTION
OF
FRENCH GULCH
AND THE
WELLINGTON-ORO MINE AND MILL SITE

# Cross Section through French Gulch at Wellington/Oro Mine
## June 1991 High Flow




**Potential Sources of Heavy Metals Pollution**

**A. Mill tailings in alluvium, saturated by French Gulch**

**B. Incident precipitation leaches mine and mill waste to water table**

**C. Mine pool from Wellington/Oro complex drains to alluvium of French Gulch**

Data from mine maps and monitoring well drill logs. Interpretation by B.K. Stover eventually enter French Creek by ground-water discharge. Extensive fracturing within the shale bedrock and faults in the area may enhance ground-water flow in the bedrock. The French Gulch area is underlain by Cretaceous shale, limestone, and quartzite; Jurassic shale and sandstone; and Tertiary monzonite and quartz monzonite porphyry (Lovering, 1934). Thin Quaternary glacial material commonly covers the bedrock. The French Gulch valley floor is filled with approximately fifty feet of glacial alluvium and colluvium that thins and pinches out along the valley side slopes (SAIC, 1993 & Stover, 1994). There are two hydrostratigraphic units that are probably hydraulically connected in the vicinity of the W-O site; an alluvial aquifer, and the underlying fractured shale bedrock. The mine workings are associated with the fractured shale and Tertiary intrusives (Figure 3).

## Purpose and Scope

The purpose of this study is to characterize the ground-water hydrology in the vicinity of the W-O mine and mill site. The objective of the study is to identify and quantify ground-water flow between the fractured shale and alluvial aquifers. The integration of the ground-water hydrology with ground-water chemistry data and geologic information will be used to evaluate the extent of ground-water transport of metals to French Creek. The scope of the study includes compiling and interpreting available data collected at French Gulch since 1990 and conducting aquifer tests on the alluvium and shale. Comparison of the ground-water chemistry between aquifers will be used to assess the degree and direction of hydraulic communication. Geologic and water chemistry data will also help characterize the fate of metals in the system. The ability to characterize, understand, and isolate sources of contamination will be very useful for any future surface and underground remediation activities. This study will also supply the EPA and State with an approach to characterize metal loadings to streams from ground-water sources at abandon mine sites. In general, previous State and EPA Region VIII investigations at inactive mine sites have not emphasized the contribution of ground-water as a potential source of contamination and transport mechanism (Wireman, pers. comm. 1994). This study represents a more complete ground-water characterization prior to remediation than typical inactive mine site characterizations.

# DATABASE AND MAPPING

A Geographic Information System (GIS) was used for database management, data manipulation, and mapping. The GIS technology utilized was GeoGraphix Exploration System (GES). GES was designed as a raster-based environment for geoscientists which specializes in cartographic information, well and geophysical data, and contour mapping. The core of the system is a relational database manager with a Microsoft Windows interface that accesses several modules which can be run on a 486 personal computer (GeoGraphix, 1991). Selected chemical and geologic data were entered into the GES database for mapping. In addition, these data were also entered in Quatro Pro (QPRO) spreadsheets for analysis and graphing.

Base maps for the area of study were constructed by digitizing paper maps (Figures 1 & 4). The paper map sources included U.S. Geological Survey (USGS) 7.5 minute topographic maps (Breckenridge and Boreas Pass Quadrangles), USGS Geologic Maps (Ransome, 1911 & Lovering, 1934), and a one inch to fifty feet scaled two foot contour topographic map produced from aerial surveys (Horizons, 1992). DMG geologist Bruce Stover assisted in spotting the monitoring well locations and other features on the Horizon topographic map. The Horizon topographic map did not indicate any projection. Known latitude and longitude registration points on the USGS topographic map were tied into the Horizon map and wells

**FIGURE 4**

**BASE MAP OF STUDY AREA**

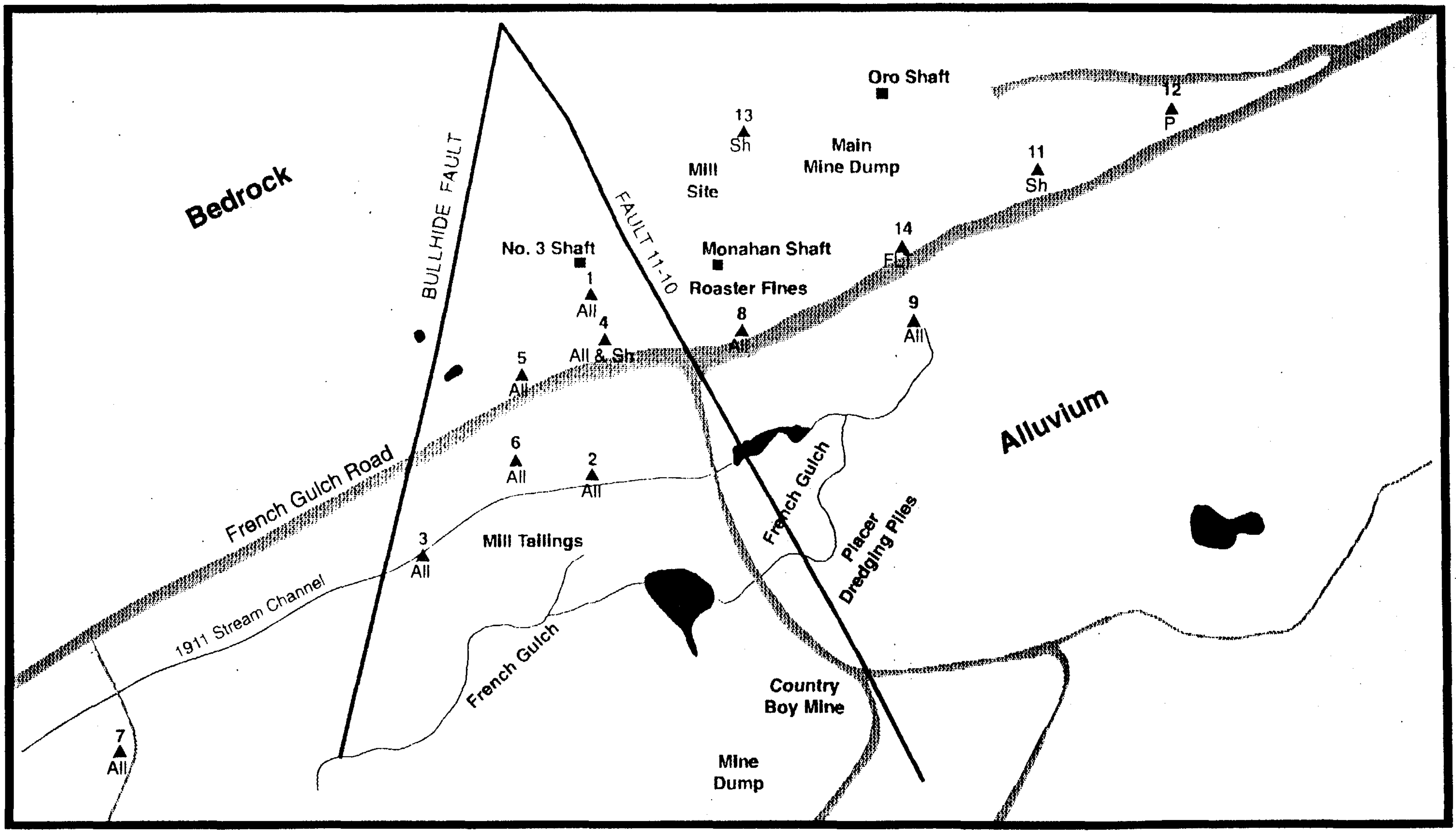
MONITORING WELL COMPLETIONS

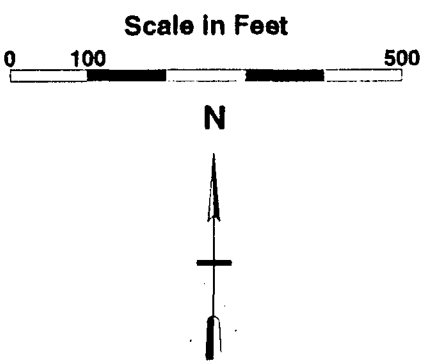
All-Alluvium

Sh-Shale

FLT-Fault(11-10)

P-Porphyry




# French Gulch

## Mine Pool Hydrology Characterization
## Base Map Study Area

Drawn by: BST Graphics
Interpretation: Art Morrissey

and other features were digitized using the USGS map's Universal Transverse Mercator projection. Prior to the aquifer tests, Bruce Stover and the author surveyed in the new observation and pump wells and checked the locations and elevations of several of the old monitoring wells. Contour maps of chemical and water level data were constructed by applying GES minimum curvature and adaptive fitting algorithms to produce a grid from the point data which was subsequently contoured. The grid surface and/or contours were eliminated outside the data control to reduce erroneous extrapolation of the data. These mapping files were downloaded to window metafiles for BST Graphics. BST Graphics produced the page size formats presented in this report.

The aquifer testing incorporated a Hermit Data Logger connected to pressure transducers in the observation and pumping wells used for the constant discharge pumping tests and in monitoring wells for the slug testing. Several observation wells water levels were also measured by hand with a electronic probe during the pump tests. The software utilized for evaluating the slug and pump test data was AQTESOLV (Geraghty and Miller, 1989). This program combines statistical parameter estimation methods with interactive graphical curve-matching techniques. QUICKFLOW (Geraghty and Miller, 1991) software was used to conduct pre-test modelling of well drawdowns for designing the pump tests. QUICKFLOW is a analytical 2D ground water flow model that can simulate steady-state and transient ground-water flow. Approximately twenty-five data points were manually selected from the Hermit Data Logger and entered into AQTESOLV which produced drawdown versus time and recovery versus time curves for the slug tests. Eighty to one hundred data points were used for the pump test drawdown and recovery curves.

## WATER CHEMISTRY

Water chemistry analyses were available from surface and ground-water samples collected since 1991. Prior to 1993 only selected metals were run on samples. The November 1993 water chemistry data included major cations and anions in addition to selected metals. Field measurements conducted on samples were commonly temperature, conductivity, and pH.

This study concentrated on ground-water chemistry from monitoring wells. The pre-1994 well development at French Gulch usually included two inch diameter PVC well casing with at least two separate five or ten foot screens (Table IV). Most of the wells were completed in the upper and lower portions of the alluvium. Many lower alluvium screens penetrated a few feet into the underlying bedrock (commonly shale). The study area base map summarizes the types of well completions (Figure 4). Metal concentrations measured from water samples prior to 1993 showed

# TABLE IV

## SUMMARY OF PRE-1994 MONITORING WELL COMPLETIONS

| WELL | TOP ALLUVIUM | TOP BEDROCK | TOTAL DEPTH | SCREENED INTERVAL(S) |
|---|---|---|---|---|
| 1 | 6' | 42'(CLAY)<br>44'(SHALE) | 50' | 22'-27'(5')<br>33'-43'(10') |
| 2 | 22' | 41'(PORPHYRY) | 47.5' | 37'-47'(10') |
| 3 | 6' | 53'(SHALE) | 55' | 15'-25'(10')<br>45'-50'(5') |
| 4 | 7' | 55'(CLAY)<br>56'(SHALE) | 64' | 20'-30'(10')<br>46'-51'(5')<br>58'-63'(5') |
| 5 | 5' | 52'(SHALE) | 55' | 20'-30'(10')<br>50'-55'(5') |
| 6 | 25' | 40'(CLAY)<br>42'(SHALE) | 54' | 34'-44'(10')<br>49'-54'(5') |
| 7 | 12' | 50'(PORPHYRY) | 52' | 18'-23'(5')<br>38'-48'(10') |
| 8 | 5' | 43'(SHALE) | 46' | 15'-20'(5')<br>35'-45'(10') |
| 9 | 17' | 51'(CLAY)<br>52'(SHALE) | 54.5' | 43'-53'(10') |
| 11 | 10' | 29'(SHALE) | 43' | 23'-28'(5')<br>38'-43'(5') |
| 12 | NONE | 10'(PORPHYRY) | 46' | 40'-45'(5') |
| 13 | 13' | 28'(SHALE) | 47' | 36'-46'(10') |
| 14 | 2.5' | 38'(SHALE)<br>101'(PORPHYRY) | 278' | 268'-278'(10') |

marked differences in water quality from the upper and lower screened intervals in wells #6, #7, and #8. Water samples collected during November 1993 did not isolate upper and lower screens except for well #8. The upper screened waters (upper alluvium) in these wells contained higher metal concentrations.

The cation-anion balance of the 1993 water analyses were evaluated by constructing a spreadsheet that converts concentrations in milligrams per liter to milliequivalents per liter and determines a cation/anion ratio (Table V). In most cases the cation/anion ratios were significantly greater than 1.00. This suggests that metal loading has caused the ground waters not to be electrically neutral or in equilibrium. The addition of metal cations to the ground-water explains cation/anion ratios greater than one and also contributes to high electrical conductivities. Because of this water imbalance between cations and anions it was not possible to classify these waters using Trilinear (Piper) diagrams (Domenico and Swartz, 1990 and Fetter, 1988). These diagrams do not account for significant concentrations of metals such as iron, zinc, and manganese, and the cation/anion imbalance. Stiff (1951) patterns were used to graphically display the major cations and anions (Figure 5). The Stiff patterns illustrate that the waters have a calcium-magnesium dominant cation facies and an extremely dominant sulfate anion facies. The high sulfate content is not unusual for mine waters due to the oxidation of pyrite and

# Table V

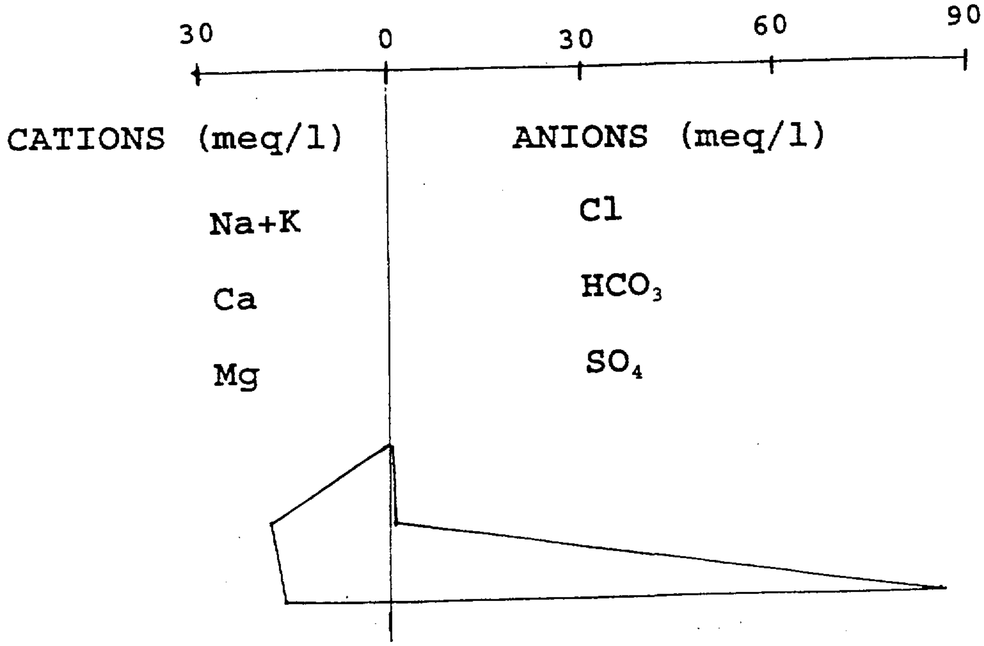
EXAMPLES OF CATION/ANION RATIOS FROM GROUND-WATER ANALYSES

| Chemical analysis | Well #1(Qal) mg/l | Date 11/17/93 meq/l | Chemical analysis | Well #7(Qal) mg/l | Date 11/17/93 meq/l | Chemical analysis | Well #13(sh) mg/l | Date 11/16/93 meq/l |
|---|---|---|---|---|---|---|---|---|
| cations | | | cations | | | cations | | |
| Na | 14.04 | 0.61 | Na | 3.93 | 0.17 | Na | 23.97 | 1.04 |
| K | 2.90 | 0.07 | K | 1.50 | 0.04 | K | 10.80 | 0.28 |
| Mg | 119.40 | 9.55 | Mg | 31.66 | 2.53 | Mg | 228.10 | 18.25 |
| Ca | 388.00 | 19.40 | Ca | 134.00 | 6.70 | Ca | 393.80 | 19.69 |
| Fe | 108.84 | 3.90 | Fe | 50.62 | 1.81 | Fe | 20.47 | 0.73 |
| Mn | 34.36 | 1.25 | Mn | 15.36 | 0.56 | Mn | 130.06 | 4.73 |
| Zn | 131.90 | 4.03 | Zn | 21.68 | 0.66 | Zn | 1495.00 | 45.73 |
| Totals | | 38.82 | Totals | | 12.48 | Totals | | 90.46 |
| anions | | | anions | | | anions | | |
| HCO3 | 78.00 | 1.28 | HCO3 | 43.00 | 0.71 | HCO3 | 23.00 | 0.38 |
| Cl | 2.45 | 0.07 | Cl | 1.69 | 0.05 | Cl | 7.49 | 0.21 |
| SO4 | 1750.00 | 36.19 | SO4 | 460.00 | 9.51 | SO4 | 4190.00 | 86.64 |
| F | 3.10 | 0.12 | F | 0.96 | 0.04 | F | 5.95 | 0.24 |
| Totals | | 37.66 | Totals | | 10.30 | Totals | | 87.47 |
| cation/anion ratio= | | 1.03 | cation/anion ratio= | | 1.21 | cation/anion ratio= | | 1.03 |

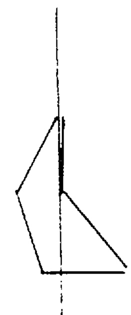
Qal-Alluvium well
sh-Shale well

FIGURE 5

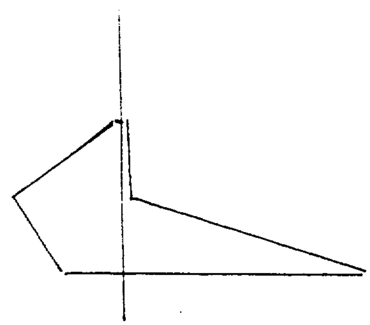
EXAMPLES OF STIFF PATTERNS




#13 SHALE WELL



#7 ALLUVIAL WELL

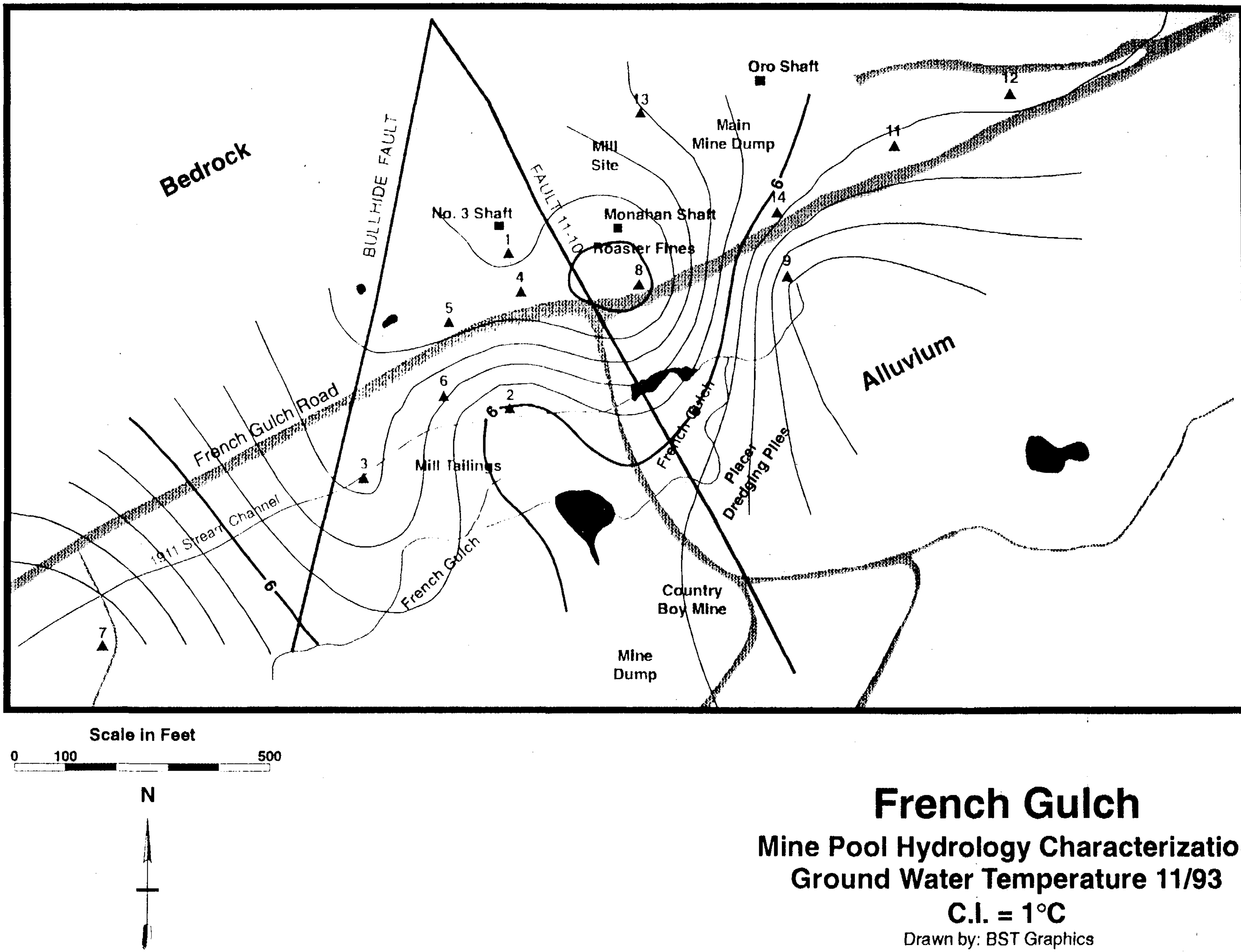


#1 ALLUVIAL WELL

other sulfide minerals. Oxidation of pyrite can also result in the formation of acidic water (Manahan, 1991). The ground-water chemistry was very similar between the shale and alluvium aquifers. Metal concentrations, sulfate concentrations, and other selected water chemistry parameters were mapped for the November 1993 samples (Figures 6 through 10). The mapping of the chemical data did not discriminate between the source of the ground-water; alluvium, shale, porphyry, or fault (Figure 4). Cadmuim, zinc, and iron concentrations (upper and lower screened concentrations were averaged for data prior to 1993) were also plotted with time and graphically displayed for the monitoring wells (Figures 11 & 12). The November 1993 temperature, conductivity, zinc, and sulfate maps for the study area indicated anomalies in the vicinity of the abandoned mine shafts and mine dump north of French Gulch Road (Figures 6 through 9). The ground-water temperature anomalies are a few degrees celsius warmer than the wells south of French Gulch Road (Figure 6). The higher temperatures correspond to higher electrical conductivities, and greater zinc and sulfate concentrations (Figures 7, 8, & 9). Lower pH values and higher cadmium concentrations also are associated with these anomalies. South of French Gulch Road, iron concentrations are highest in the vicinity of the mill tailings (Figure 10). Concentration versus time for cadmium, iron, and zinc were also distinctive for wells north of French Gulch Road (Figure 11). Zinc and iron

FIGURE 6

GROUND-WATER TEMPERATURE MAP
NOVEMBER 1993



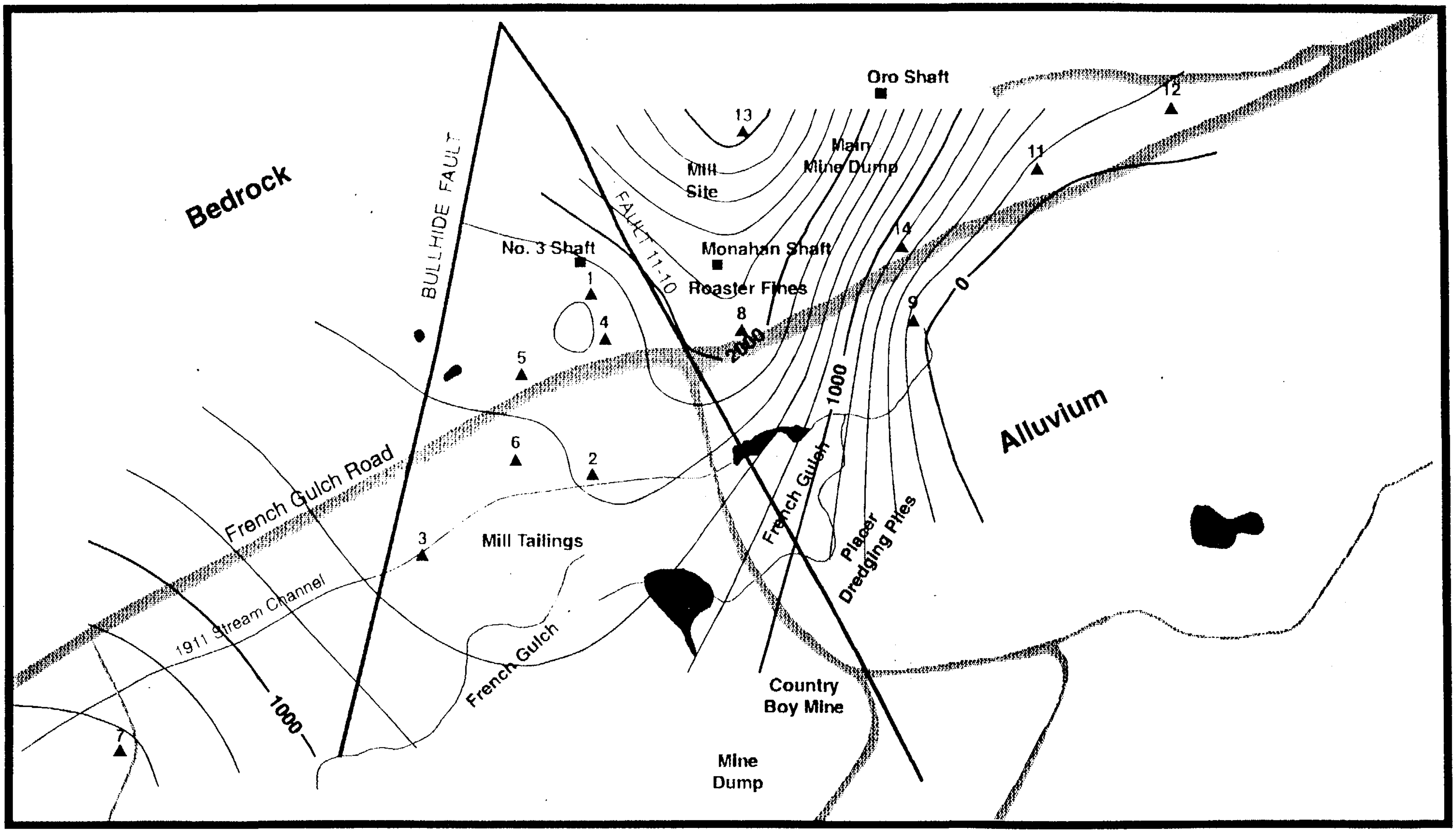

# French Gulch

## Mine Pool Hydrology Characterization
## Ground Water Temperature 11/93
## C.I. = 1°C

Drawn by: BST Graphics

FIGURE 7

GROUND-WATER ELECTRICAL CONDUCTIVITY MAP
NOVEMBER 1993




Scale in Feet

0 100 500

N

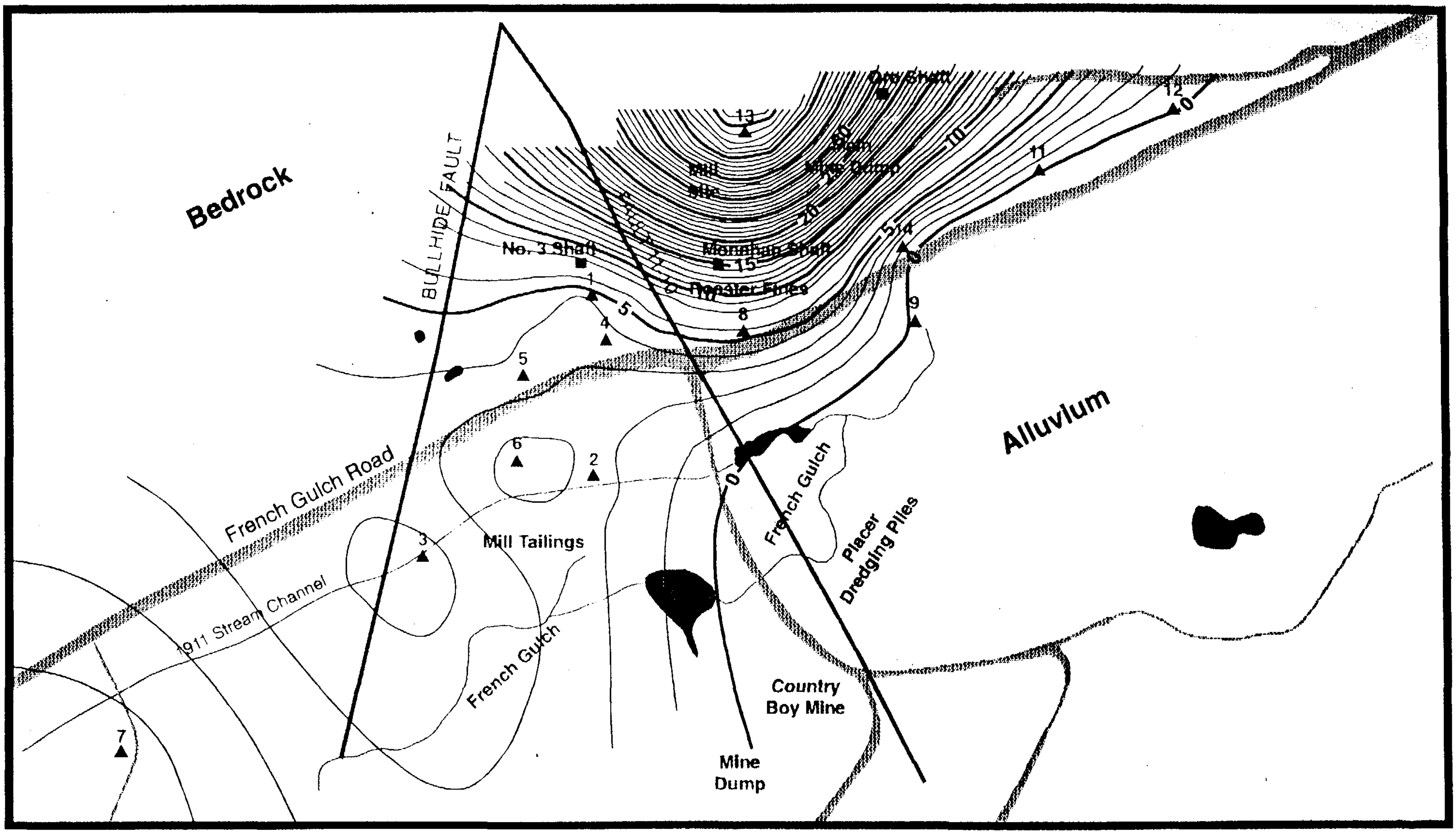
# French Gulch

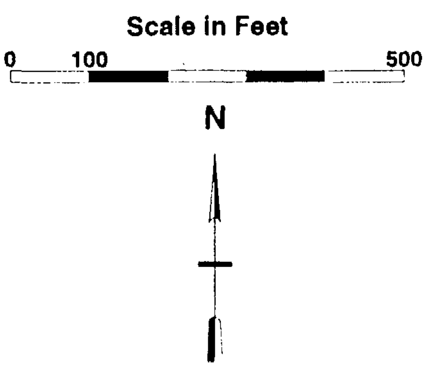
## Mine Pool Hydrology Characterization
## Ground Water Conductivity 11/93
## C.I. = 200 umhos/cm

Drawn by: BST Graphics

FIGURE 8

GROUND-WATER
ZINC CONCENTRATION MAP
NOVEMBER 1993



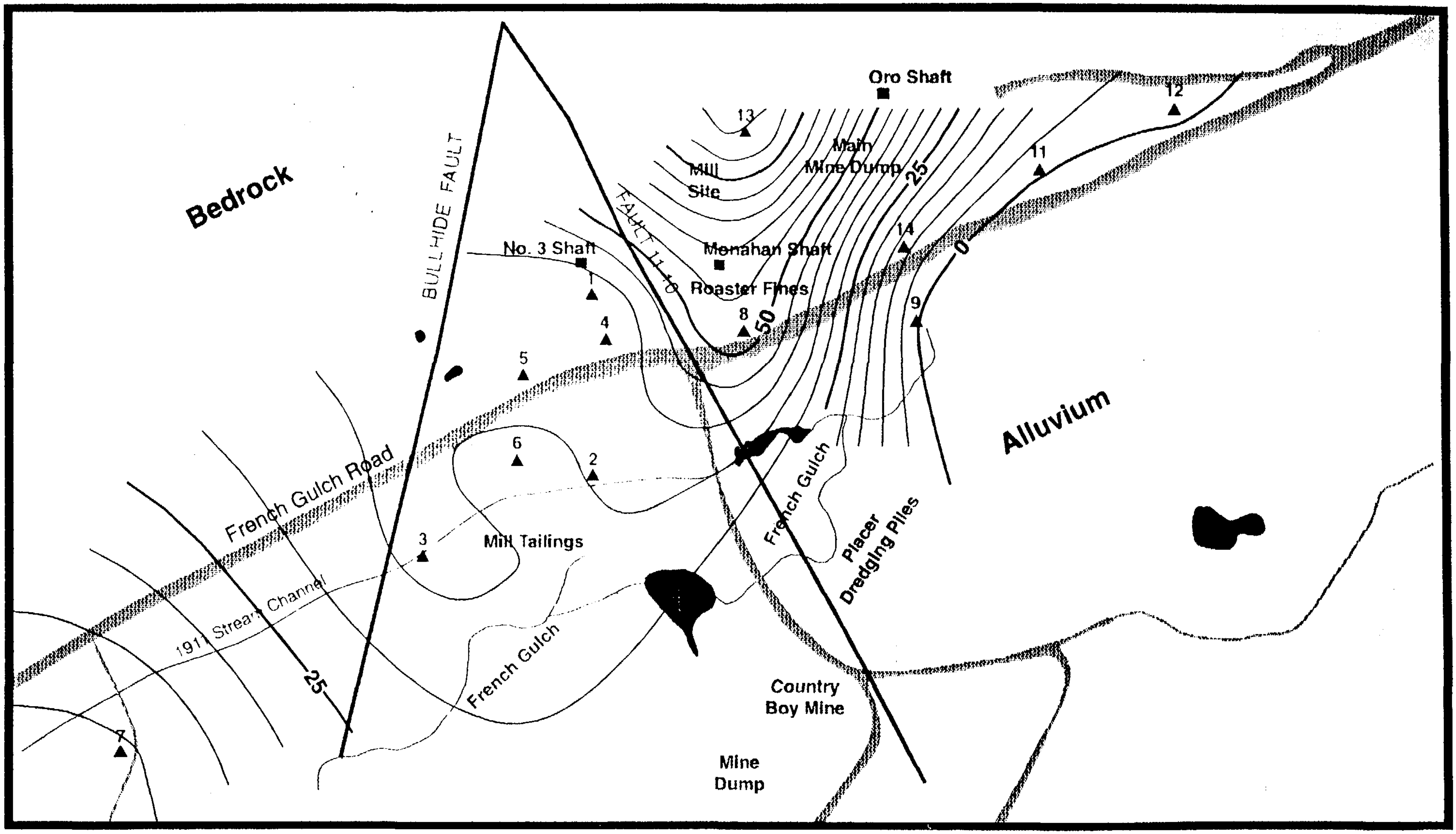

# French Gulch

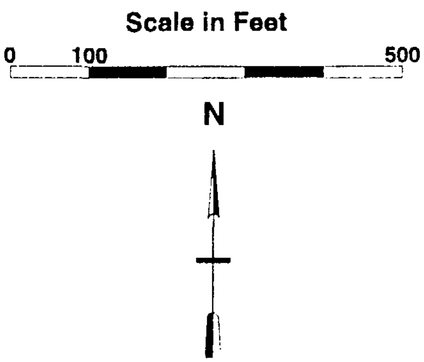
## Mine Pool Hydrology Characterization
## Ground Water Zn Concentration 11/93
## C.I. = 1 meq/l

Drawn by: BST Graphics

FIGURE 9

GROUND-WATER
SULFATE CONCENTRATION MAP
NOVEMBER 1993



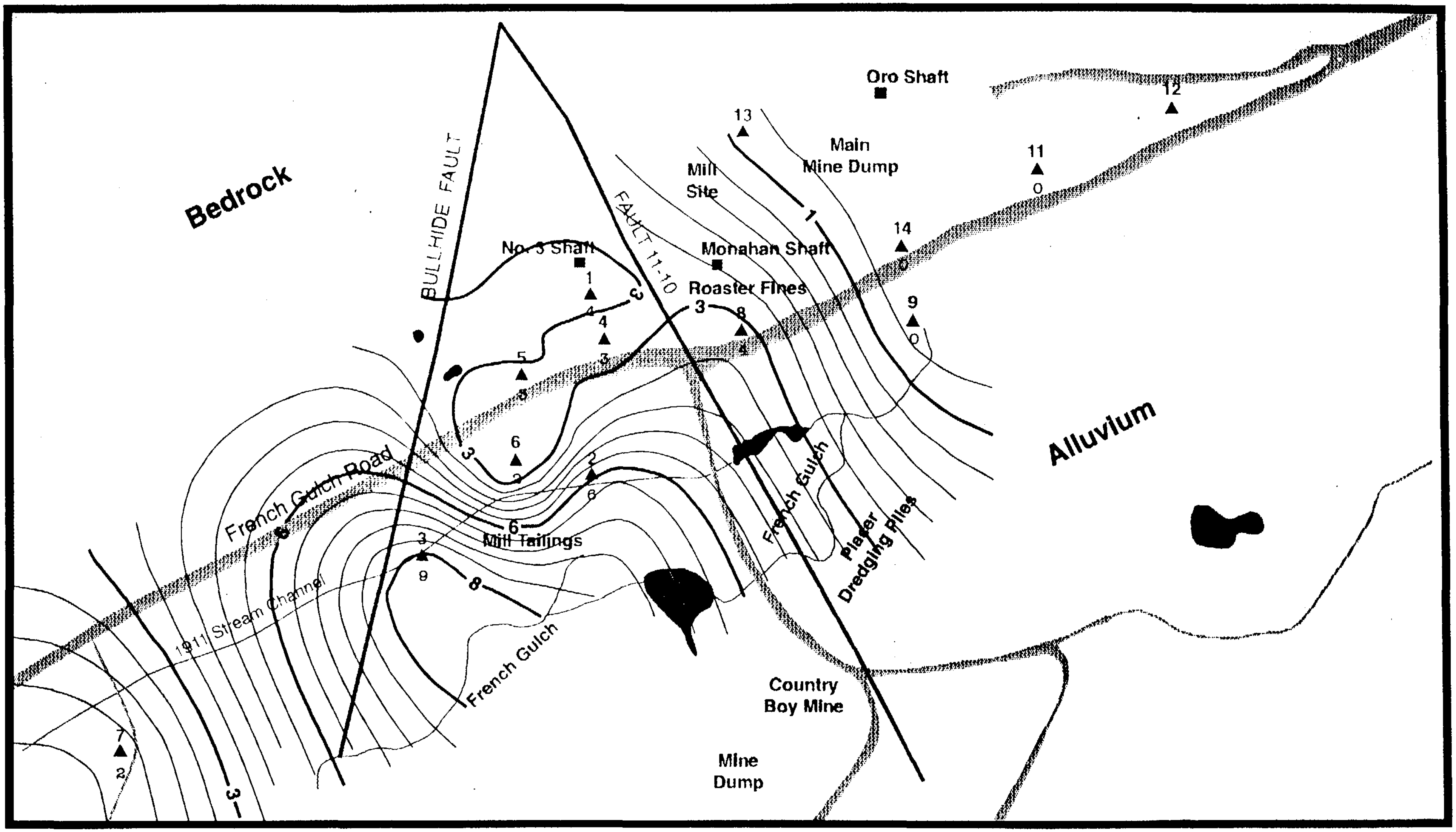

# French Gulch

**Mine Pool Hydrology Characterization**
**Ground Water Sulfate Concentrations 11/93**
**C.I. = 5 meq/l**

Drawn by: BST Graphics

FIGURE 10

GROUND-WATER
IRON CONCENTRATION
NOVEMBER 1993




Scale in Feet

0 100 500

N

# French Gulch

## Mine Pool Hydrology Characterization
## Ground Water Fe Concentration 11/93
## C.I. = 0.5 meq/l

Drawn by: BST Graphics

FIGURE 11

SELECTED METAL CONCENTRATIONS
(Zn,Fe,Cd)
VERSUS
TIME
FOR
WELL #1
NORTH OF FRENCH GULCH ROAD

French Gulch Well 1

# Well Water Chemistry

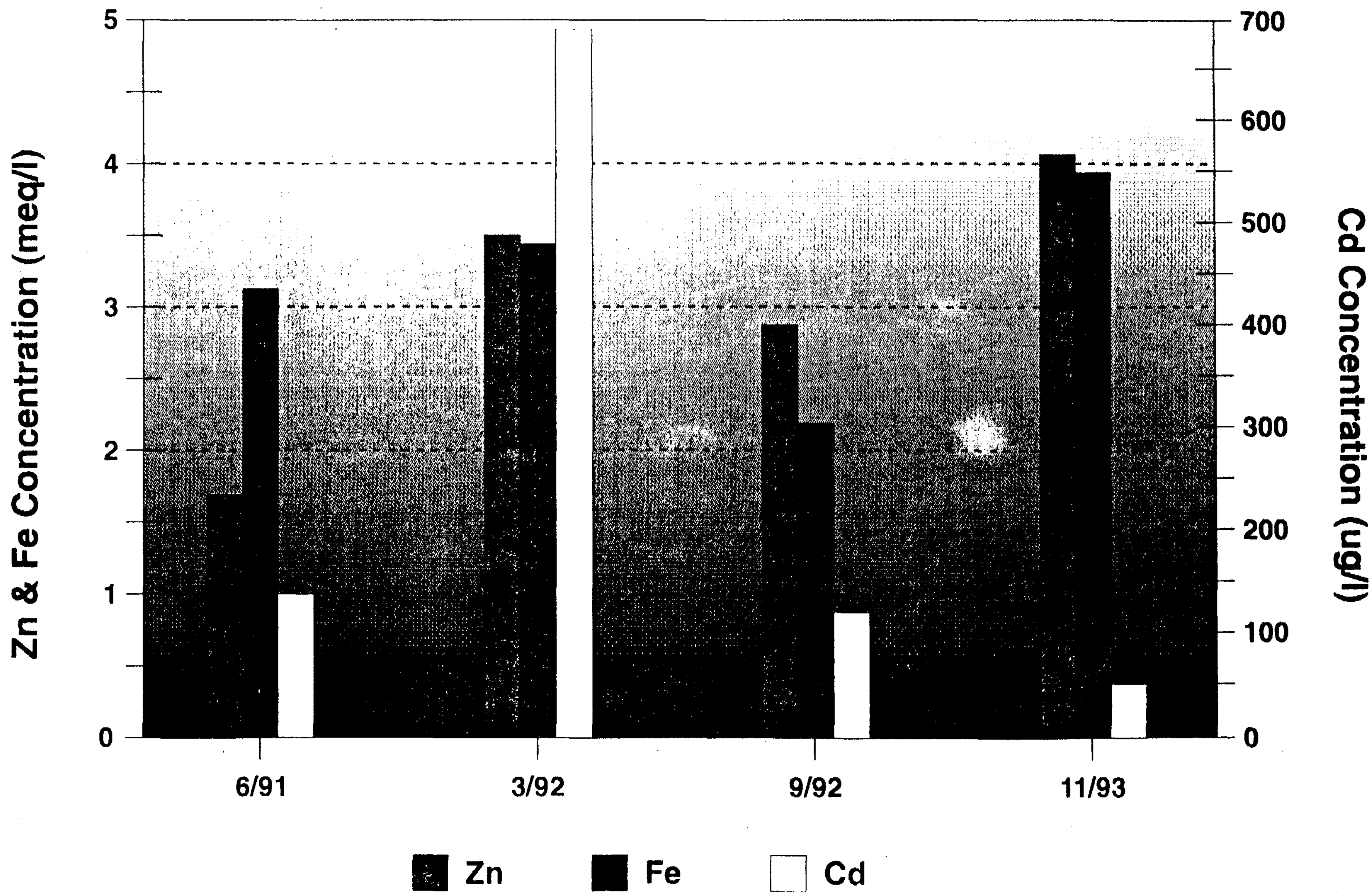
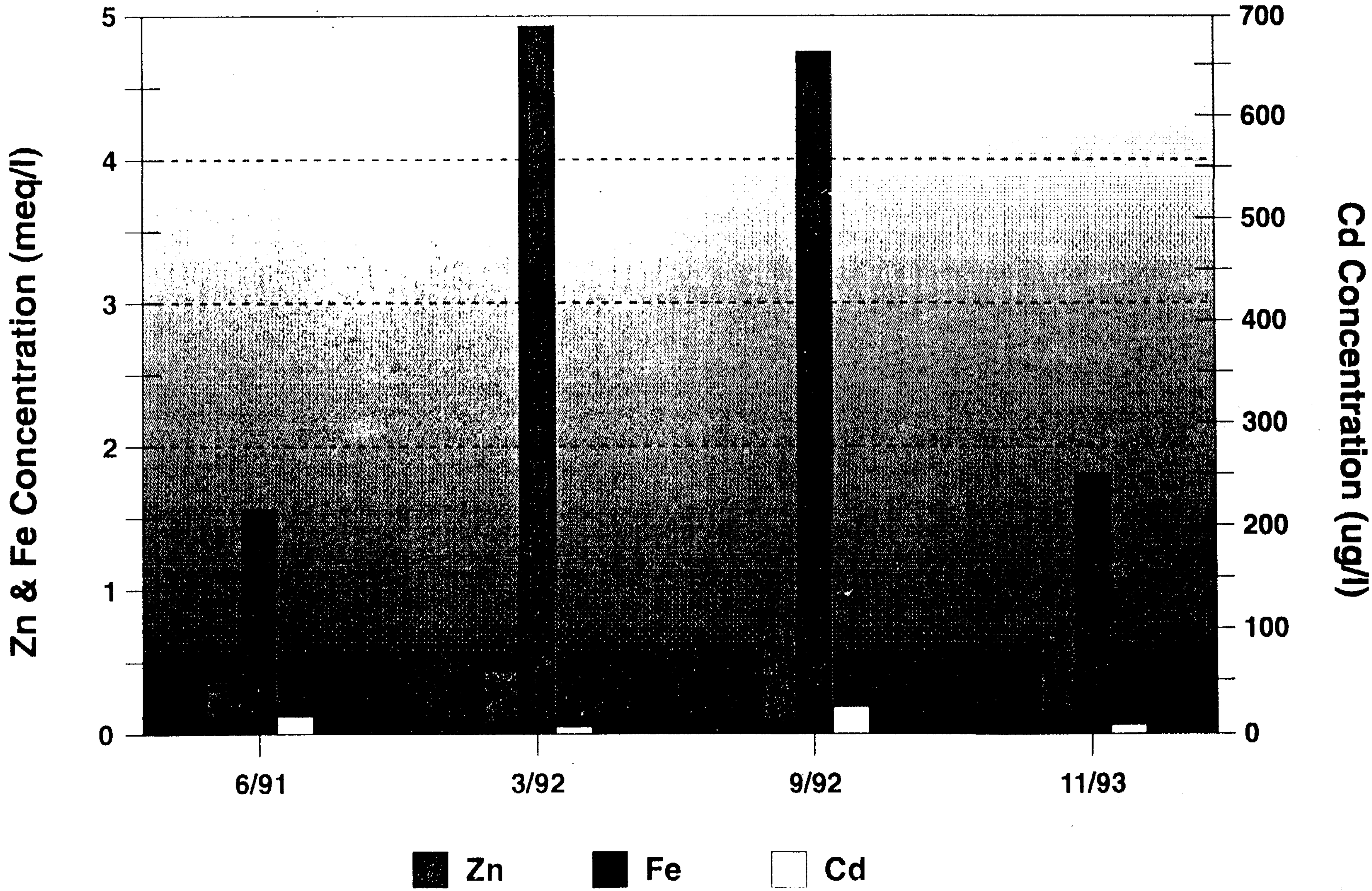


FIGURE 12

SELECTED METAL CONCENTRATIONS
(Zn,Fe,Cd)
VERSUS
TIME
FOR
WELL #7
SOUTH OF FRENCH GULCH ROAD

French Gulch Well 7

# Well Water Chemistry



concentrations are relatively comparable and do not fluctuate significantly while cadmium concentrations are relatively high and fluctuate with time. In contrast, wells in the vicinity of French Gulch south of the road have higher iron and lower zinc and cadmium concentrations (Figure 12). Iron concentrations also tend to fluctuate with time. The higher iron concentrations are beleived to be due to the oxidation of pyrite. The most contaminated ground-water occurs in the shale well #13 and the mine pool. The least contaminated ground-water has been observed from upstream eastern wells #9, #11, #12, and #14. These wells are completed in alluvium, shale (sampled from lower shale screen), porphyry, and the 11-10 fault, respectively (Table IV).

## AQUIFER TESTING

### Slug Testing

The purpose of conducting slug tests was to obtain estimates of hydraulic conductivities (K) for the alluvial and shale aquifers. These tests provide a time efficient and cost-effective method for acquiring order of magnitude estimates of K that can be applied to pre-pump test models to determine optimum pump rates (Q) and expected drawdowns of the pump and observation wells during constant discharge pump tests. The pre-pump test models were used to design the constant disharge tests. A one inch diameter by ten foot long PVC pipe filled with sand was constructed for use as a slug tool. This slug tool averaged about five feet head displacement in the two inch diameter French Gulch monitoring wells. A best curve fitting solution for the drawdown/recovery curves from the alluvial slug tests using AQTESOLV (Geraghty & Miller, 1989) was the Bouwer-Rice (1976) unconfined aquifer model (Figures 13 & 14). The shale drawdown/recovery curves matched the Cooper et al. (1967) type curves for a confined aquifer (Figures 15 & 16). The values for the shale storativity (S) (0.02-0.006) suggest that the shale is behaving as a semi-confined aquifer. Table VI summarizes the results of the slug testing. Hydraulic conductivities of 25 to 65 ft/day for the alluvium is fairly typical for sand and gravel (Kruseman & DeRidder, 1991). The shale K of 1.8 to 2.1 ft/day is very high for typical shale or clay (i.e. $1x10^{-2}$ - $1x10^{-6}$ ft/day)(Kruseman & DeRidder, 1991). The aquifer thickness (b) used for the slug test analyses was the saturated shale or alluvial aquifer thickness above the bottom of the well screen.

## Constant Discharge Tests

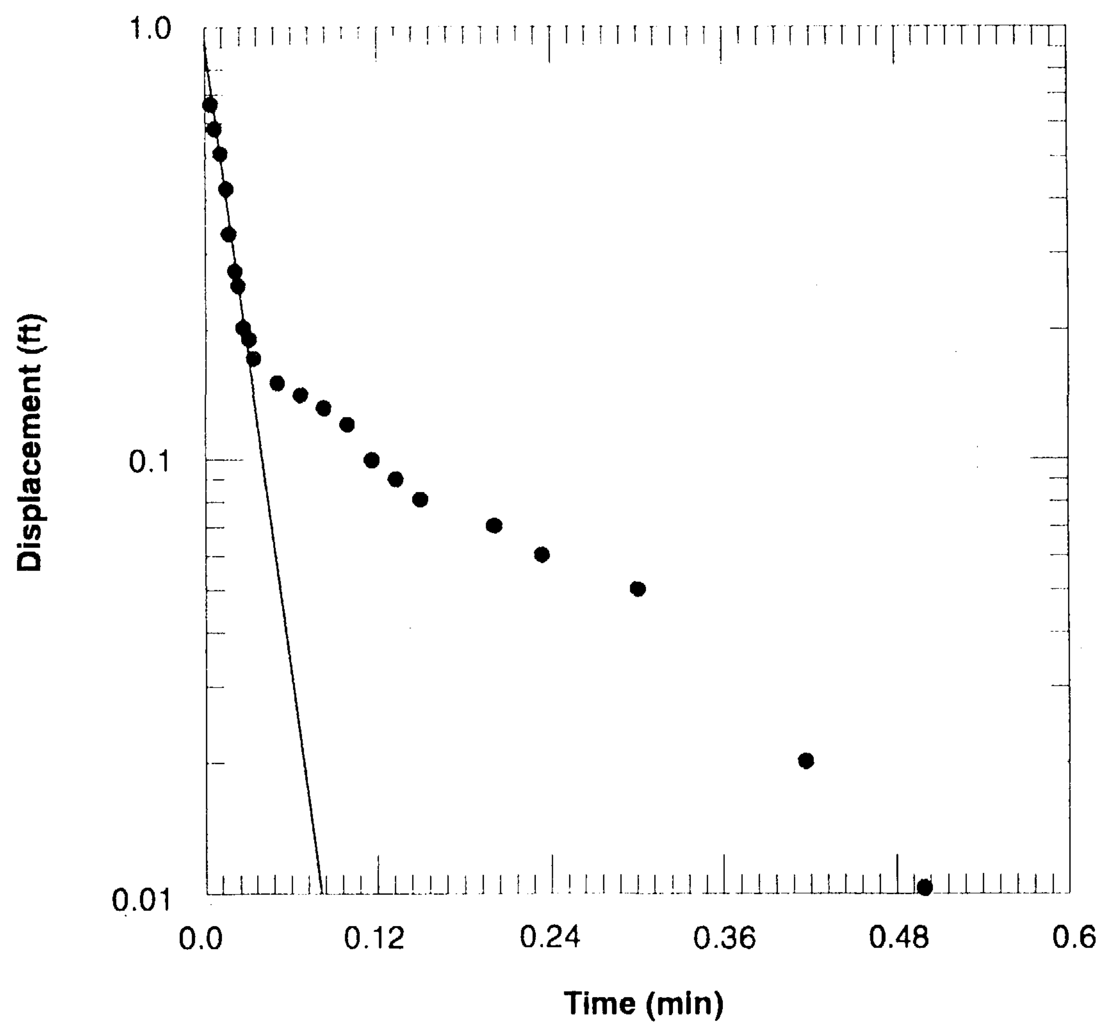
Three wells were drilled in October 1994 for the purpose of conducting twenty-four hour constant discharge pump tests on the

FIGURE 13

WELL #1
(ALLUVIUM)
AQTESOLV CURVE-MATCHING
FOR A
RISING HEAD SLUG TEST

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

## French Gulch Mine Hydrology - Well 01RH




**DATA SET**
wm01rhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
01

**OBS. WELL**
01

**ESTIMATED PARAMETERS**
K = 0.0572 ft/min
y0 = 0.9166 ft.

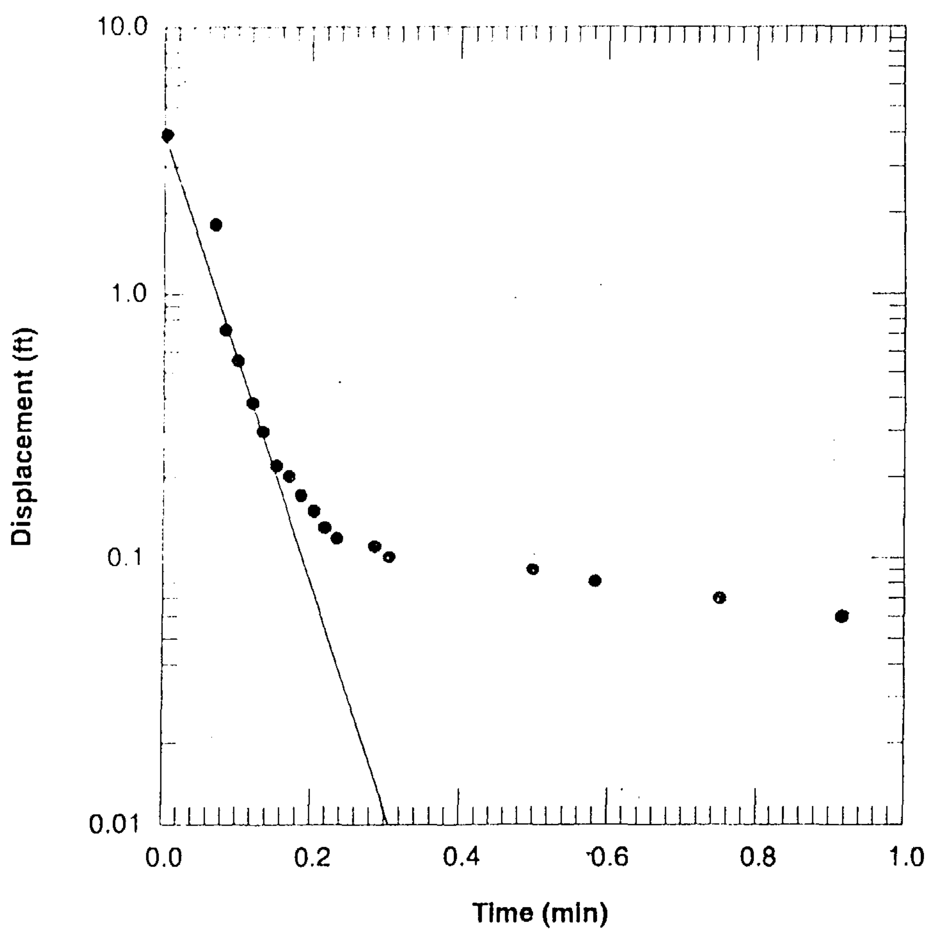
**TEST DATA**
HO = 4 ft
rc = 0.833 ft
rw = 0.1667 ft
L = 13 ft
b = 29 ft
H = 29 ft

FIGURE 14

WELL #1
(ALLUVIUM)
AQTESOLV CURVE-MATCHING
FOR A
FALLING HEAD SLUG TEST

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

## French Gulch Mine Hydrology - Well 01FH




**DATA SET**
wm01fhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
01

**OBS. WELL**
01

**ESTIMATED PARAMETERS**
K = 0.02021 ft/min
y0 = 4.061 ft.

**TEST DATA**
HO = 4 ft
rc = 0.833 ft
rw = 0.1667 ft
L = 13 ft
b = 29 ft
H = 29 ft

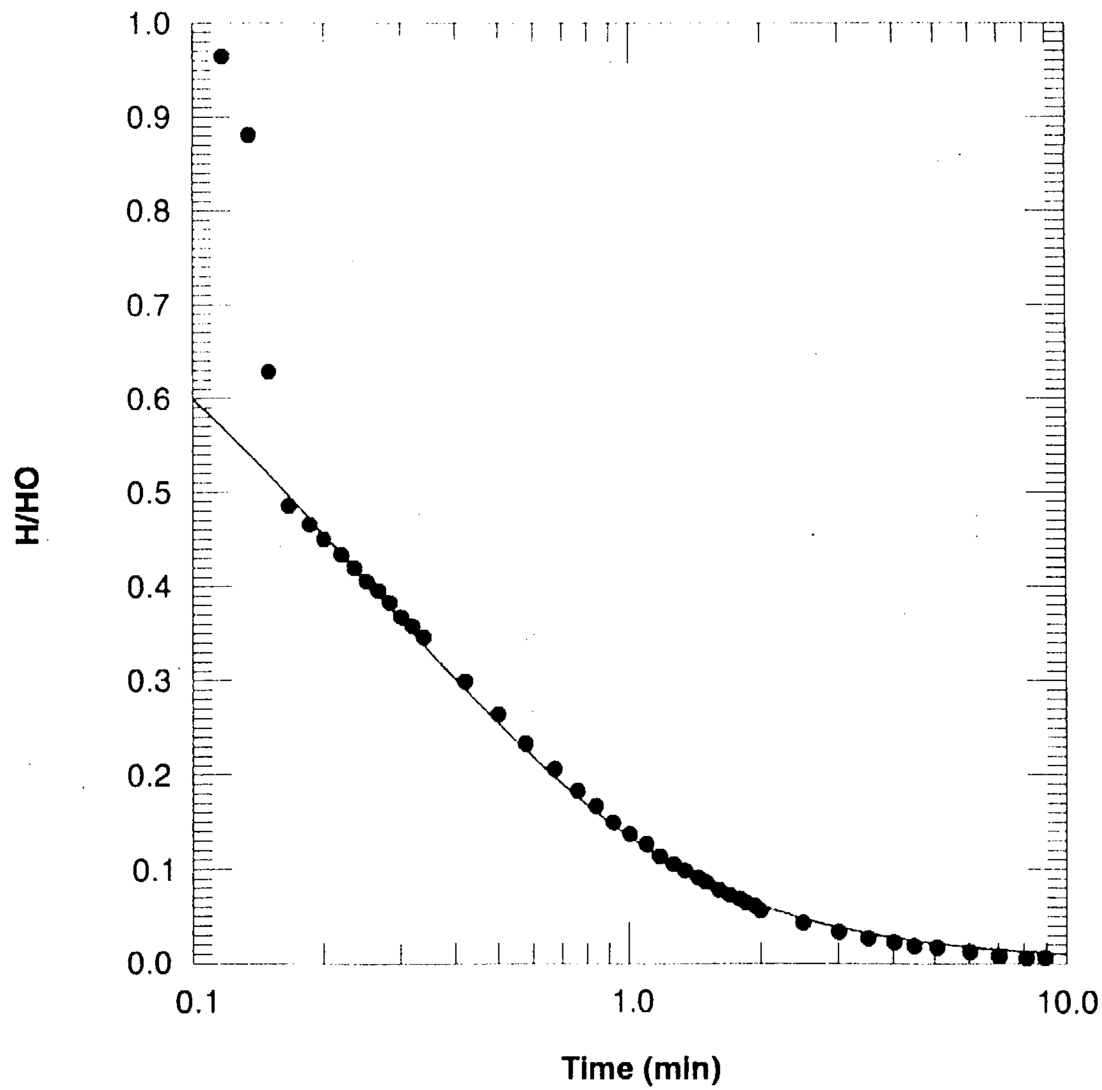
01FH.CDR

FIGURE 15

WELL #13
(SHALE)
AQTESOLV CURVE-MATCHING
FOR A
RISING HEAD SLUG TEST

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

## French Gulch Mine Hydrology - Well 13RH




**DATA SET**
wm13rhst.dat
10/17/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
13

**OBS. WELL**
13

**ESTIMATED PARAMETERS**
T = 0.01945 $ft^2$/min
S = 0.0201

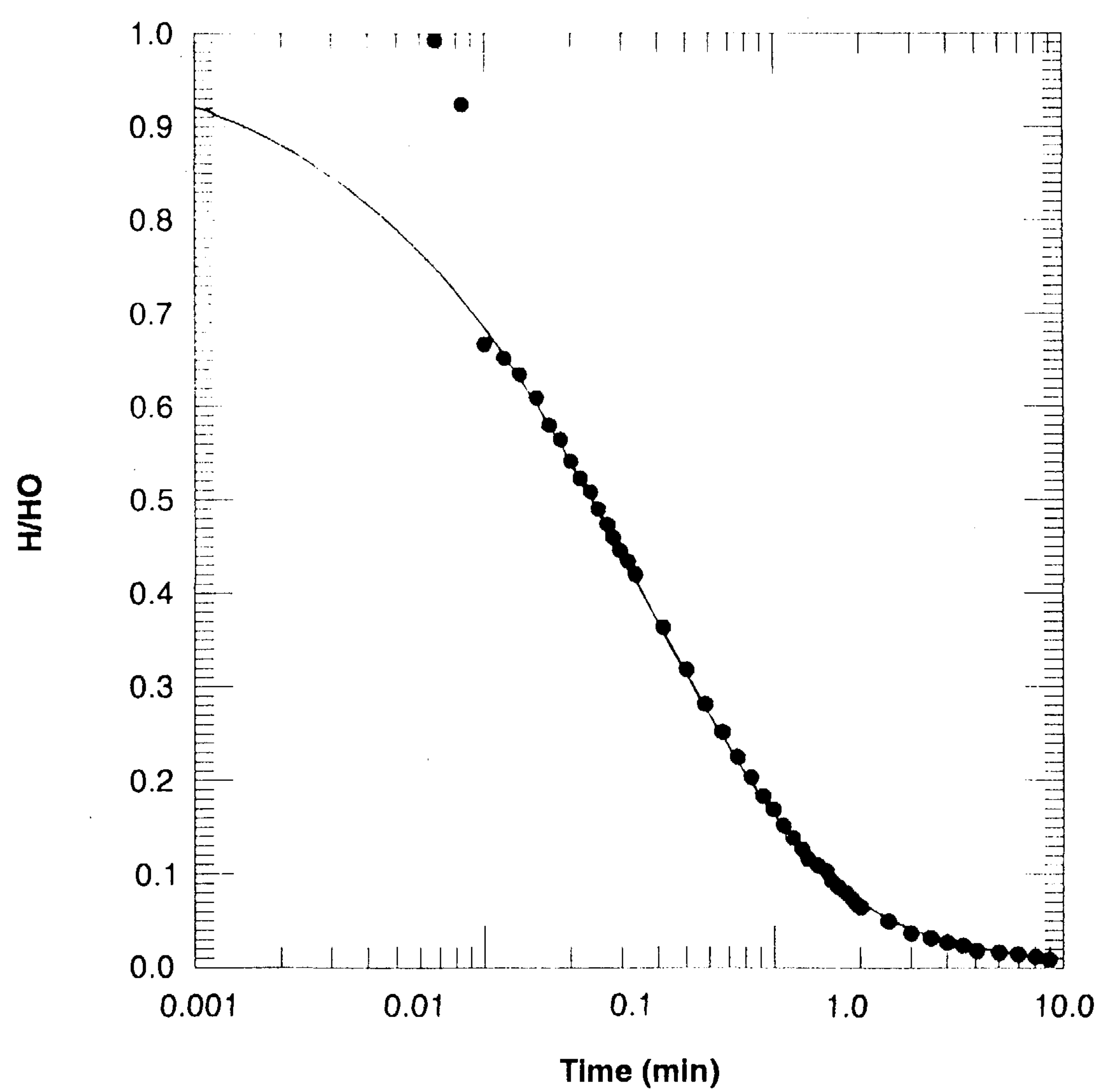
**TEST DATA**
HO = 5.3 ft
rc = 0.08333 ft
rw = 0.1667 ft

FIGURE 16

WELL #13
(SHALE)
AQTESOLV CURVE-MATCHING
FOR A
FALLING HEAD SLUG TEST

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 13FH




**DATA SET**
wm13fhst.dat
10/14/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
13

**OBS. WELL**
13

**ESTIMATED PARAMETERS**
T = 0.02046 $ft^2$/min
S = 0.005569

**TEST DATA**
HO = 5 ft
rc = 0.08333 ft
rw = 0.1667 ft

# Table VI

SLUG TEST RESULTS

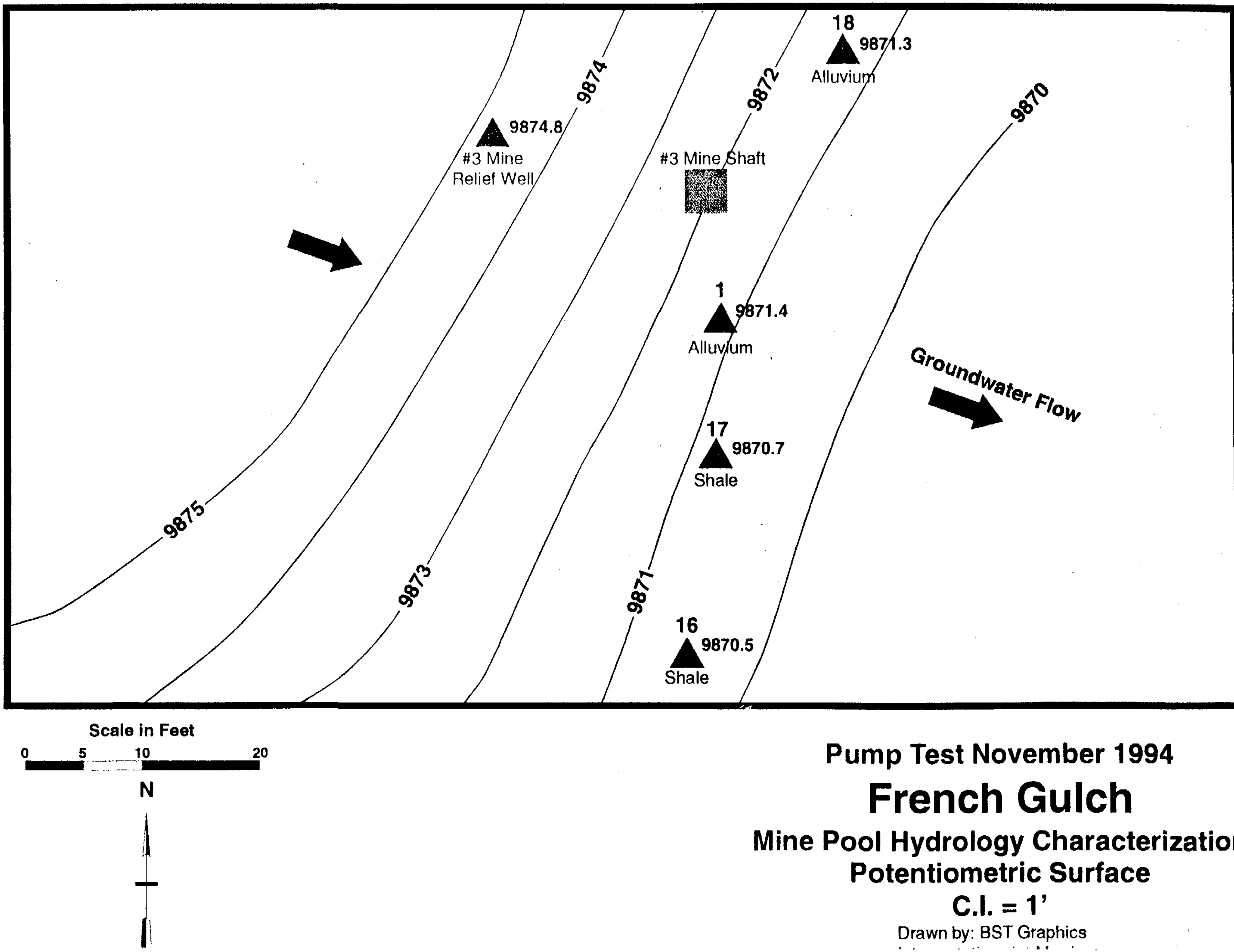
| TEST | | TEST QUALITY | TRANSMISSIVITY(T) ft^2/min | TRANSMISSIVITY(T) ft^2/day | HYDRAULIC CONDUCTIVITY(K) ft/min | HYDRAULIC CONDUCTIVITY(K) ft/day | STORATIVITY (S) | THICKNESS(b) feet |
|---|---|---|---|---|---|---|---|---|
| SHALE WELLS | | | | | | | | |
| #11 | RISING HEAD | excellent | 0.01902 | 27.40 | 0.00148 | 2.1 | 0.009 | 13 |
| | FALLING HEAD | excellent | 0.0173 | 24.90 | 0.00133 | 1.9 | 0.004 | |
| #13 | RISING HEAD | v. good | 0.01945 | 28.00 | 0.00122 | 1.8 | 0.02 | 16 |
| | FALLING HEAD | v. good | 0.02046 | 29.50 | 0.00128 | 1.8 | 0.006 | |
| | | AVG. | 0.01906 | 27.45 | 0.00133 | 1.9 | | |
| | | | std.dev. | 1.66 | | 0.12 | | |
| ALLUVIUM WELLS | | | | | | | | |
| #1 | RISING HEAD | fair | 1.6588 | 2388.7 | 0.0572 | 82.4 | | 29 |
| | FALLING HEAD | fair | 0.58609 | 844 | 0.02021 | 29.1 | | |
| #3 | RISING HEAD | fair | 1.71494 | 2469.5 | 0.04513 | 65 | | 38 |
| | FALLING HEAD | good | 1.20042 | 1728.6 | 0.03159 | 45.5 | | |
| #7 | RISING HEAD | good | 1.2873 | 1853.7 | 0.03678 | 53 | | 35 |
| | FALLING HEAD | v.good | 0.64155 | 923.8 | 0.01833 | 26.4 | | |
| #8 | RISING HEAD | poor | 0.42537 | 612.5 | 0.01289 | 18.6 | | 33 |
| | FALLING HEAD | fair | 0.91773 | 1321.5 | 0.02781 | 40 | | |
| | | AVG. | 1.05403 | 1517.7875 | 0.03124 | 45 | | |
| | | | std.dev. | 660.15238475 | | 19.95 | | |

shale and alluvial aquifers. Two of the wells were constructed of four inch diameter PCV casing and twenty foot well screens. These wells were developed as pumping wells (#17 shale & #18 alluvium). In addition, one two inch PVC cased well was constructed as a observation shale well (#16 shale). Figure 17 shows the relative locations of these wells. Other wells that were used for observing drawdowns during the pumping tests were #1 alluvium, #3 Mine shaft relief well, #4 alluvium & shale, #5 alluvium, #8 alluvium, and #13 shale (Figure 4). The #4 well had a packer set between the alluvial and shale screens for the purpose of isolating the aquifers during the shale and alluvial pump tests. Analysis of drawdown data from this well indicated the packer did not effectively isolate the aquifers.

QUICKFLOW (Geraghty & Miller, 1991) predicted a drawdown of seven feet for the alluvial pump well #18 after 30 minutes using a K of 45 ft/day and a constant discharge (Q) of 80 gpm. The discharge rate of 80 gpm immediately pumped #18 dry during the constant discharge pre-test. A 15 gpm Q was used during the 24 hour pumping test. A 8 foot drawdown after 30 minutes of pumping was observed in well #18 using the pump rate of 15 gpm. The large difference between the QUICKFLOW modelling drawdown and observed drawdown was probably due to poor well development and a lower actual K for the alluvial aquifer. QUICKFLOW (Geraghty & Miller, 1991) predicted a drawdown of thirteen feet for the shale aquifer

FIGURE 17

LOCATION OF WELLS
USED IN THE
AQUIFER CONSTANT DISCHARGE TESTS
AND THEIR
POTENTIOMETRIC SURFACE




**Pump Test November 1994**

# French Gulch

## Mine Pool Hydrology Characterization
## Potentiometric Surface
## C.I. = 1'

Drawn by: BST Graphics

pump well #17 after 30 minutes using a K of 1.9 ft/day and a Q of 10 gpm. Seventeen feet of drawdown was observed during the 30 minute constant discharge pre-test applying a pump rate Q of 14 gpm. A pump rate of 12 gpm was used for the 24 hour constant discharge shale test.

Drawdown was observed in all wells monitored during the alluvium and shale constant discharge tests (Table VII). This is conclusive evidence that the mine, alluvial aquifer, and the shale bedrock are in hydraulic communication. AQTESOLV best curve matching of drawdown curves for the alluvial and shale aquifers occurred with the leaky semi-confined aquifer solutions (Figures 18 & 19)(Hantush and Jacob, 1955, and Hantush, 1960).

The alluvium is a water table or unconfined aquifer. A logarithmic plot of time-drawdown response for water table aquifers typically displays three distinctive parts (Domenico and Schwartz, 1990). The very early time-drawdown data follows the Theis equation (Theis, 1935) and confined conditions where water is released from storage due to the elastic compression of the aquifer and the expansion of water. This is characterized by small storativity values (Kruseman and De Ridder, 1991). The effects of gravity drainage takes over with time and tends to flatten the response curve causing an apparent increase in the storativity over its confined value. During this delayed gravity drainage period the time-drawdown response is a function of the ratio of horizontal

## Table VII

MAXIMUM DRAWDOWN PUMPIMG TESTS

| | ALLUVIUM TEST | | | | SHALE TEST | | | |
|---|---|---|---|---|---|---|---|---|
| WELL | TYPE | DRAWDOWN (ft) | Distance Pump Well(ft) | Time(mins)* | TYPE | DRAWDOWN (ft) | Distance Pump Well(ft) | Time(mins)* |
| #1 | OW(Qal) | 1.764 | 25 | 1010 | OW(Qal) | 1.145 | 14 | 1470 |
| #3Mine | OW | 1.01 | 32 | 1004 | OW | 0.93 | 31.5 | 220** |
| #4 | OW(Qal) | 1.08 | 110 | 1120 | OW(sh) | 1.05 | 72 | 1172 |
| #5 | OW(Qal) | 0.67 | 210 | 1030 | OW(Qal) | 0.90 | 170 | 1485 |
| #8 | OW(Qal) | 0.48 | 250 | 904 | OW(Qal) | 0.51 | 250 | 1424 |
| #13 | OW(sh) | 0.10 | 330 | 905 | OW(sh) | 0.11 | 380 | 1327 |
| #16 | OW(sh) | 1.00 | 51 | 1003 | OW(sh) | 2.693 | 16.5 | 1470 |
| #17 | OW(sh) | 1.64 | 35.5 | 1020 | PW(sh) | 14.99 | 0 | 1480 |
| #18 | PW(Qal) | 7.961 | 0 | 1000 | OW(Qal) | 0.941 | 35.5 | 1470 |

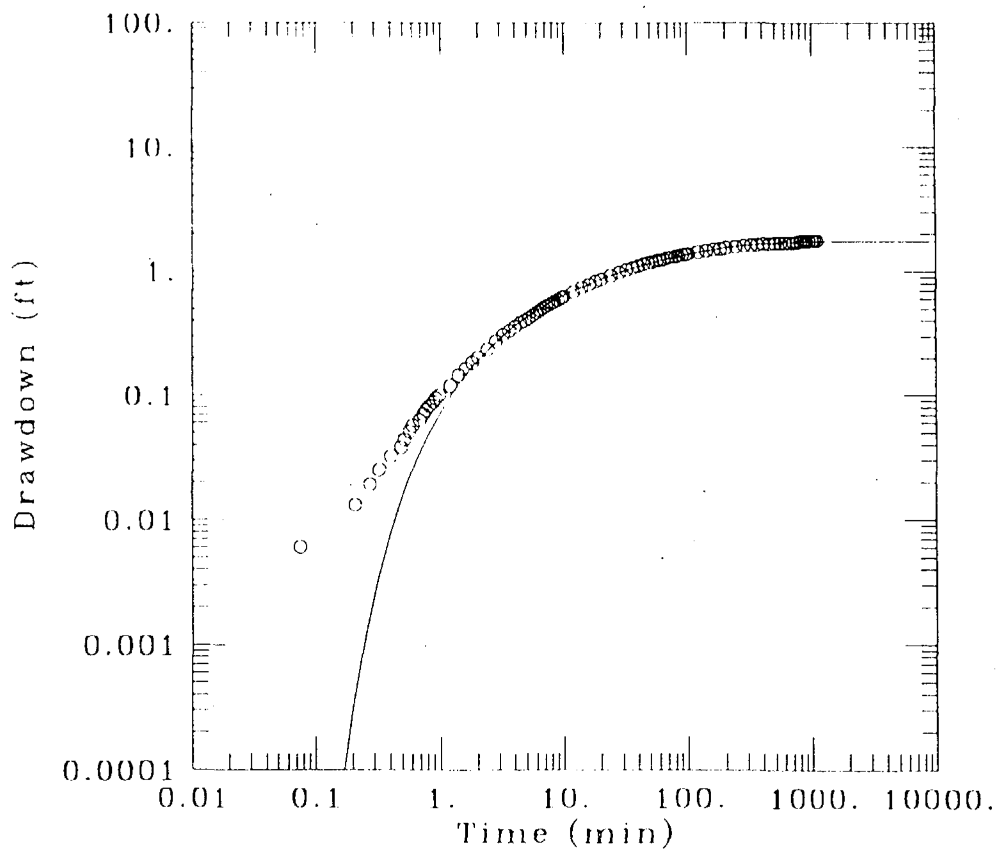
Qal-Alluvium
sh-shale
OW-observation well
PW-pump well
* time from start of pumping
**transducer malfunction after 220 mins.

FIGURE 18

AQTESOLV CURVE-MATCHING
FOR THE
ALLUVIAL OBSERVATION WELL #1
DURING THE
ALLUVIAL PUMP TEST

| | |
|---|---|
| Research Project | Client: EPA/CMG/CDH |
| Project No.: 94 1 | Location: Breckenridge, CO. |

# French Gulch Hydrology - QAL Pt, 1QalDD




DATA SET:
1aloda.dat
11/10/94

AQUIFER TYPE:
Leaky
SOLUTION METHOD:
Hantush
TEST DATE:
11/1/94
TEST WELL:
18
OBS. WELL:
1

ESTIMATED PARAMETERS:
T = 0.4434 $ft^2/min$
S = 0.00297
r/B= 0.1004

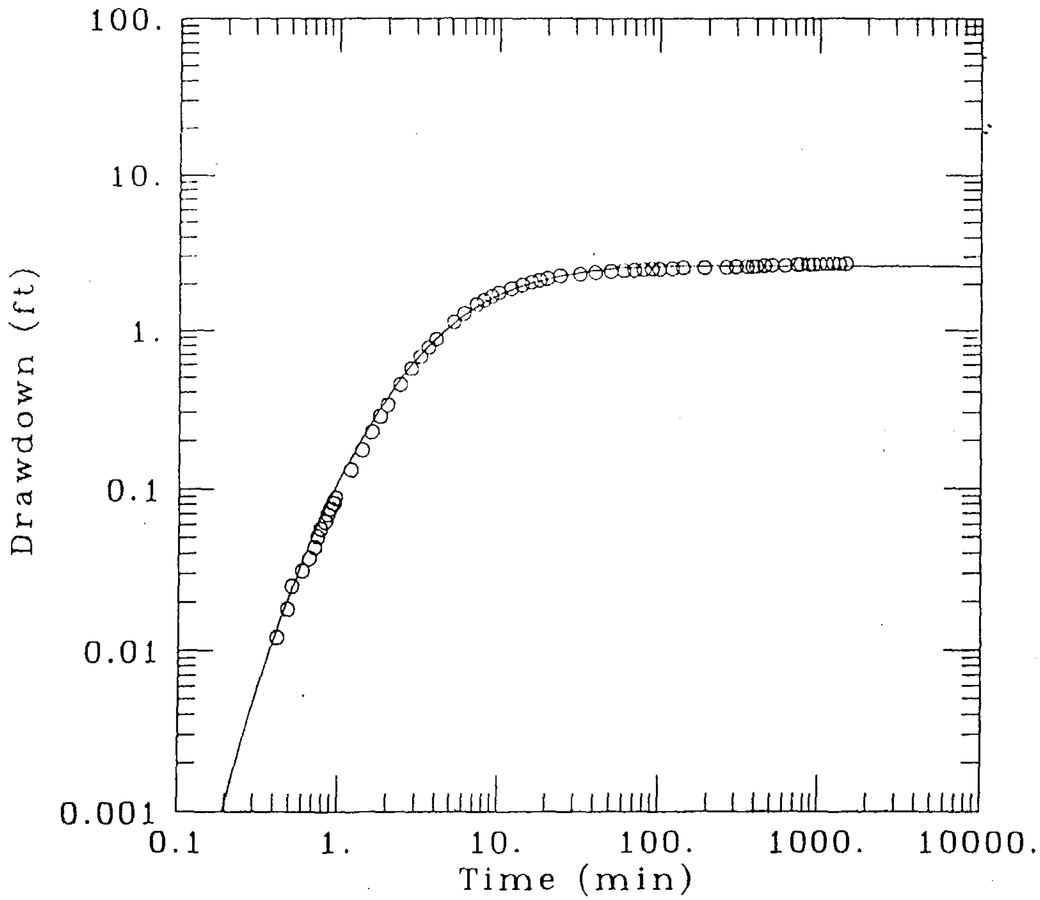
TEST DATA:
Q = 2.005 $ft^3/min$
r = 25. ft
rc = 0.1667 ft
rw = 0.25 ft

FIGURE 19

AQTESOLV CURVE-MATCHING
FOR THE
SHALE OBSERVATION WELL #16
DURING THE
SHALE PUMP TEST

| Research Project | Client: EPA/CMG/CDH |
| --- | --- |
| Project No.: 94-1 | Location: Breckenridge, CO. |

# French Gulch Hydrology - Sh PT, 16shDD




DATA SET:
16sods.dat
11/11/94

AQUIFER TYPE:
Leaky
SOLUTION METHOD:
Moench
TEST DATE:
11/3/94
TEST WELL:
17
OBS. WELL:
16

ESTIMATED PARAMETERS:
T = 0.1776 $ft^2$/min
S = 0.0009597
r/B = 0.1905
β = 0.002229
Sw = 82.59
a = 0.007542

TEST DATA:
Q = 1.604 $ft^3$/min
r = 16.5 ft
rc = 0.1667 ft
rw = 0.25 ft

to vertical conductivity, the thickness of the aquifer, and the distance to the pump well (Domenico and Schwartz, 1990). For later time, the time-drawdown response will again follow the Theis-type curve when the storativity no longer increases with time and represents the specific yield of the unconfined aquifer. For pumping wells in a unconfined aquifer the distance to the pump well is zero and there would be no observable delayed gravity drainage response. This was the case with the alluvium pump well no. 18 where storativity values of around 0.3 represent the specific yield of the aquifer (Table VIII). It is believed that the alluvial drawdown curves for the observation wells represent early time conditions and delayed watertable response. The pumping tests were not run long enough to obtain late time Theis-type curve conditions. Thus, the time-drawdown response curves for these wells are similar to leaky aquifers tests with calculated "storativity" values falling between the confined value and the specific yield for the aquifer (Table VIII). Consequently, the AQTESOLV unconfined aquifer with delayed gravity response solutions were not successful for analyzing the alluvial drawdown curves (Neuman, 1975). In addition, using the r/B ratios (distance r divided by leakage factor B) from the alluvial well drawdown curves for estimating vertical conductivities (Kv) are not reliable because of the unknown recharge contributions between delayed gravity drainage response and leakage from the shale aquifer.

# Table VIII

CONSTANT DISCHARGE PUMPING TEST

| WELL | TRANSMISSIVITY(T) ft^2/min | ft^2/day | HORIZONTAL HYDRAULIC CONDUCTIVITY(K) ft/min | ft/day | STORATIVITY (S) | THICKNESS(b) feet | AQUIFER TYPE | METHOD AQTESOLV (1991) |
|---|---|---|---|---|---|---|---|---|
| ALLUVIUM DRAWDOWN TEST (Q=15 GPM) | | | | | | | | |
| #18 PW | 0.1252 | 180.29 | 0.0046 | 6.7 | 0.334 | 27 | LEAKY | Hantush & Jacob(no storage aquitard) |
| | 0.1672 | 240.77 | 0.0062 | 8.92 | 0.4647 | 27 | LEAKY | Hantush & Jacob(storage aquitard) |
| | 0.1482 | 213.41 | 0.0055 | 7.9 | 0.2211 | 27 | LEAKY | Moench |
| | 0.1347 | 193.97 | 0.005 | 7.2 | 0.2672 | 27 | | Cooper & Jacob |
| #1 OW | 0.4434 | 638.50 | 0.0143 | 20.6 | 0.00297 | 31 | LEAKY | Hantush & Jacob(no storage aquitard) |
| | 0.4879 | 702.58 | 0.0157 | 22.66 | 0.00246 | 31 | | Cooper & Jacob |
| #5 OW | 1.172 | 1687.68 | 0.255 | 36.69 | 0.00089 | 46 | LEAKY | Moench |
| SHALE DRAWDOWN TEST (Q=12 GPM) | | | | | | | | |
| #17 PW | 0.117 | 168.48 | 0.0025 | 3.58 | 0.0091 | 47 | LEAKY | Moench |
| #16 OW | 0.1776 | 255.74 | 0.0039 | 5.68 | 0.0096 | 45 | LEAKY | Moench |
| | 0.1527 | 219.89 | 0.0033 | 4.89 | 0.0017 | 45 | | Cooper & Jacob |

PW - PUMP WELL
OW - OBSERVATION WELL

The low values of 6 to 8 ft/day for horizontal conductivity (Kh) in the alluvial pump well #18 are probably due to poor well efficiency. Kh values of 20 to 37 ft/day from the observation wells are more representative of the alluvial aquifer. Kh for the shale aquifer data ranged from 3.6 to 4.9 ft/day (Table VIII). Vertical conductivities (Kv) for the shale aquifer were derived by applying the r/B ratios using Walton (1960) Kv solution (Table IX). The shale Kv ranged from 0.03 to 0.84 ft/day. These calculated vertical conductivities may be suspect due to the unknown contribution of recharge due to gravity drainage which is influence by distance to the pumping well. The shale Kv values increase when the observation wells are closer to the pumping well! The vertical and horizontal conductivities for the shale aquifer are very high for typical shale values. These high values are due to the fractured and faulted nature of the shale bedrock.

## GROUND-WATER FLOW

Static water levels (SWL) were measured in monitoring wells in feet below ground surface since 1991. These data were converted to an elevation above sea level using a spreadsheet (Table X). Pre-pump static water levels were also measured for wells monitored during the constant discharge pump testing in November 1994. Small

# Table IX

VERTICAL HYDRAULIC CONDUCTIVITY SHALE AQUIFER

| WELL-COMPLETION | R/B | VERTICAL HYDRAULIC CONDUCTIVITY(Kv)* ft/min | ft/day | DISTANCE PUMP WELL | AQUIFER TYPE | METHOD AQTESOLV (1991) |
|---|---|---|---|---|---|---|
| SHALE DRAWDOWN TEST (Q=12 GPM) | | | | | | |
| #16 OW - SHALE | 0.1905 | 0.00058** | 0.84 | 16.5 | LEAKY | Moench |
| ALLUVIUM DRAWDOWN TEST (Q=15 GPM) | | | | | | |
| #16 OW-SHALE | 0.05565 | 2.3E-05*** | 0.03 | 51 | LEAKY | Moench |
| #17 OW-SHALE | 0.1433 | 0.0003*** | 0.46 | 35.5 | LEAKY | Moench |

OW-OBSERVATION WELL
* Walton (1960)
** Calculation of Kv used Kh(shale)=5.68 ft/day, shale aquitard thickness(b') of 25 ft, & shale aquifer thickness(b) of 45 ft
*** Calculation of Kv used Kh(alluvium)=25 ft/day, shale aquitard thickness(b') of 25 ft, & shale aquifer thickness(b) of 45 ft

# Table X

FRENCH GULCH MONITORING WELLS WATER LEVELS

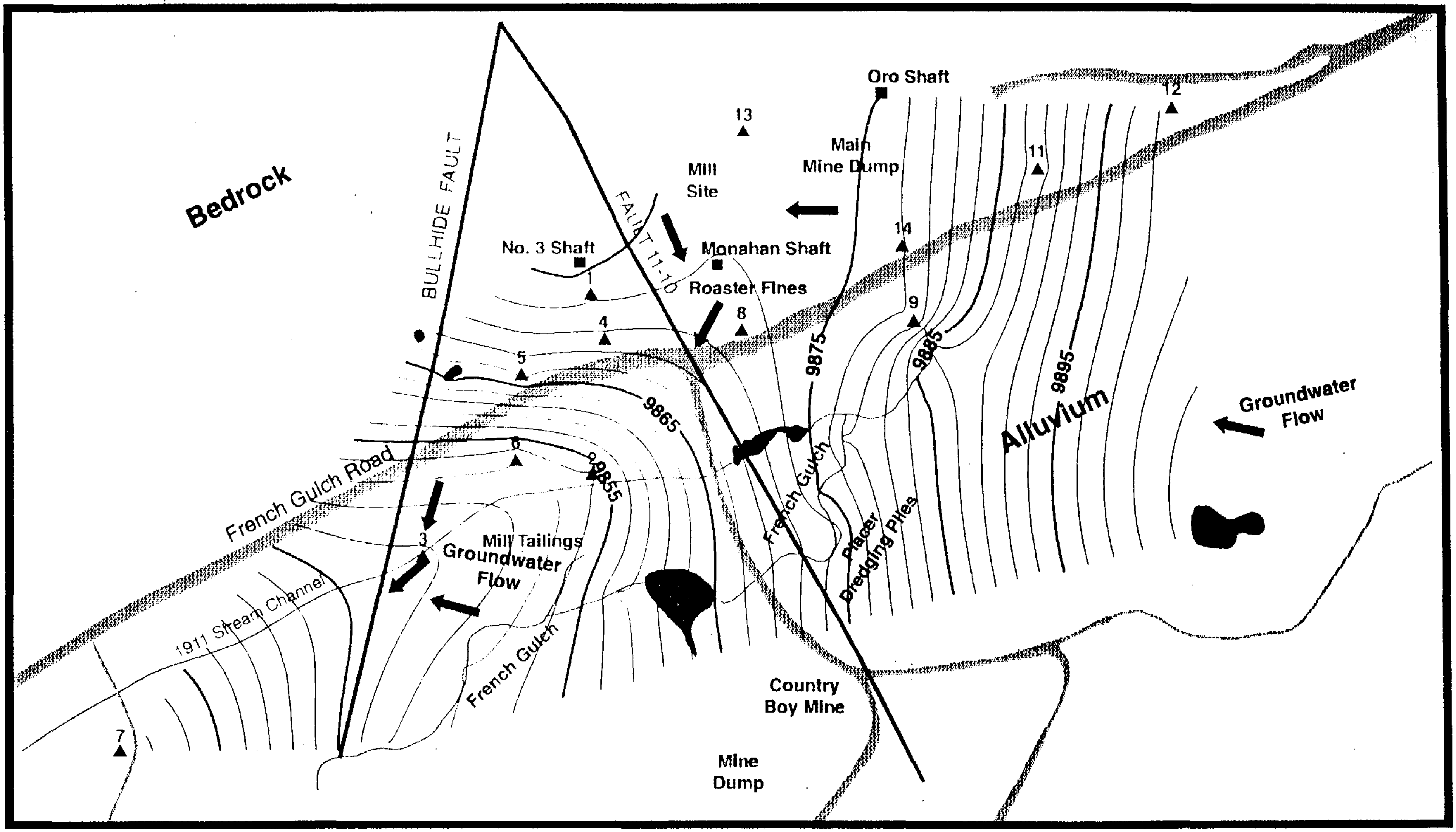
| WELL | TYPE | SURFACE ELEVATION | WATER LEVELS 11/94 below GL | elevation | 8/22-23/94 below GL | elevation | 11/16/93 below GL | elevation | 7/13/93 below GL | elevation | 6/21/93 below GL | elevation | 3/25-26/92 below GL | elevation | 6/11-12/91 below GL | elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| #14 | FLT | 9895.00 | | | 18 40 | 9876 60 | | | | | | | | | | |
| #5 | All | 9873.58 | | | 5.10 | 9868 48 | 6.00 | 9867.58 | 0.00 | 9873.58 | | | 8.00 | 9865.58 | 2.00 | 9871.58 |
| #4 | Sh & All | 9880.24 | | | | | 10 25 | 9869.99 | 4.50 | 9875.74 | | | 12.50 | 9867.74 | 6.83 | 9873.41 |
| #1 | All | 9882.10 | 10 80 | 9871.30 | 9.50 | 9872 60 | 10 50 | 9871.60 | 4.00 | 9878.10 | 3.00 | 9879.10 | 10.50 | 9871.60 | 5.00 | 9877.10 |
| #8 | All | 9882.98 | | | 10.70 | 9872 28 | 11.30 | 9871.68 | 4.00 | 9878.98 | 4.00 | 9878.98 | | | 8.00 | 9874.98 |
| #7 | All | 9840 41 | | | 12 30 | 9828.11 | 13 00 | 9827.41 | 12.00 | 9828.41 | | | 12.67 | 9827.74 | 12.17 | 9828.24 |
| #2 | All | 9866.02 | | | 14 10 | 9851.92 | 15 00 | 9851.02 | 10.00 | 9856.02 | 9.00 | 9857.02 | 13.67 | 9852.35 | 6.35 | 9859.67 |
| #3 | All | 9860 72 | | | 14.70 | 9846.02 | 16.00 | 9844.72 | 14.00 | 9846.72 | 14.75 | 9845.97 | 14.50 | 9846.22 | | |
| #6 | All | 9866.82 | | | 16.70 | 9850 12 | 17.00 | 9849.82 | 15.00 | 9851.82 | 13.75 | 9853.07 | 18.33 | 9848.49 | 6.50 | 9860.32 |
| #9 | All | 9894 00 | | | 17 35 | 9876.65 | 18.00 | 9876.00 | | | | | | | | |
| #13 | Sh | 9903.27 | | | 29 65 | 9873 62 | 30.00 | 9873.27 | | | | | | | | |
| #12 | P | 9930.00 | | | 28 80 | 9901.20 | 31.00 | 9899.00 | | | | | | | | |
| #11 | Sh | 9915.00 | | | 28.20 | 9886.80 | 31.00 | 9884.00 | | | | | | | | |
| #3Mine | Mine | 9885.76 | 10 96 | 9874 80 | 9.52 | 9876.24 | | | | | 6.67 | 9879.00 | | | 12.00 | 9873.76 |
| #16 | Sh | 9881.65 | 11 15 | 9870.50 | | | | | | | | | | | | |
| #17 | Sh | 9882.13 | 11.43 | 9870.70 | | | | | | | | | | | | |
| #18 | All | 9882.89 | 11.59 | 9871.30 | | | | | | | | | | | | |
| Oro Mine | Mine | 9958.89 | | | 84.80 | 9874.09 | | | | | | | | | | |

differences were observed in water head between the alluvial, shale, and mine wells (Figure 17). The #3 Mine Relief Well (SWL) was measured at 9874.8' above sea level, the alluvium SWL was between 9871.3' to 9870.4', and the shale SWL was between 9870.5' to 9870.7'. If these head differences are significant and consistent throughout the study area, the mine workings and the alluvial aquifer would be discharging into the shale aquifer during at least the low flow periods. It was decided to map all the well, mine, and surface water elevations as one potentiometric surface (i.e. top of water table) since the pumping tests indicated that the mine, shale, and alluvium are hydraulically connected and they have similar head elevations (Figure 20). This is an assumption that may not be accurate throughout the study area. Surface elevations of water bodies (French Creek & ponds) were determined from the Horizon (1992) topographic map. Drawdown was observed in monitoring wells nos. 8 and 13 east of the 11-10 fault during the constant discharge pump tests. It was interpreted that the faults in the study area are not barriers and do not significantly effect ground-water flow since there were no boundaries observed in the drawdown data during the constant discharge tests and there was drawdown in wells across the 11-10 fault from the pumping wells.

Figure 20 is the potentiometric surface or top of water table for low flow conditions in November 1993. French Creek was diverted around the mill tailings in 1992. This diversion was

FIGURE 20

POTENTIOMETRIC SURFACE MAP
LOW FLOW NOVEMBER 1993




Scale in Feet

0 100 500

Direction of Ground Water Flow

N

# French Gulch

## Mine Pool Hydrology Characterization
## Low Flow Potentiometric Surface
## C.I. = 2'

Drawn by: BST Graphics

Interpretation: Art Morrissey

constructed east of the road to the Country Boy Mine which is upstream from the mill tailings (Figure 20). Prior to this diversion, French Creek was seeping underneath the mill tailings and discharging just south of the tailings. The diversion was done by the State to reduce the metal mobilization associated with the ground-water leaching of the mill tailings. Surface water elevations for this diversion were incorporated in the 1993 potentiometric map. The diversion water elevations were inferred from cross-sections included in the construction specifications. Static water levels were also plotted with time for the monitoring wells. Wells north of French Creek Road exhibited large water elevation fluctuations between low and high flow conditions (Figure 21). In contrast, wells in the vicinity of the old French Gulch stream channel did not experience significant seasonal variations in water elevations (Figure 22).

A potentiometric surface represents the total head in an aquifer measured at some elevation above a datum. Water flows from high to low head perpendicular to the potentiometric surface contours (Figures 17 & 20). The potentiometric map shows a very steep hydraulic gradient (I) around 0.05 to 0.1. The map also indicates that there is localized ground-water flow a significant distance from French Gulch in the vicinity of the abandoned mine shafts and mine dump site north of French Gulch Road south into French Gulch valley as shown by the arrows on the map. The

French Gulch

# Monitoring Well 1

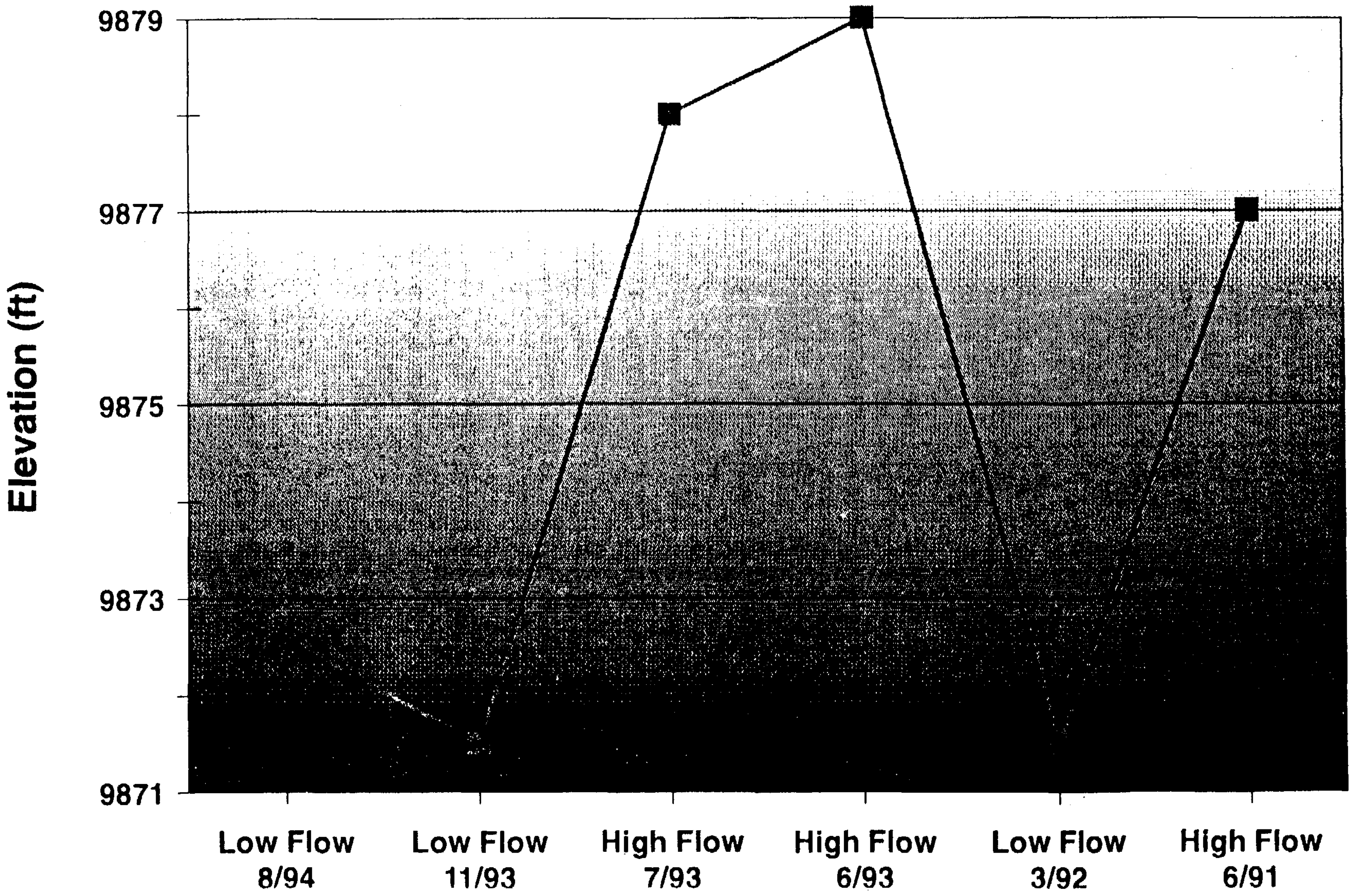


FIGURE 21

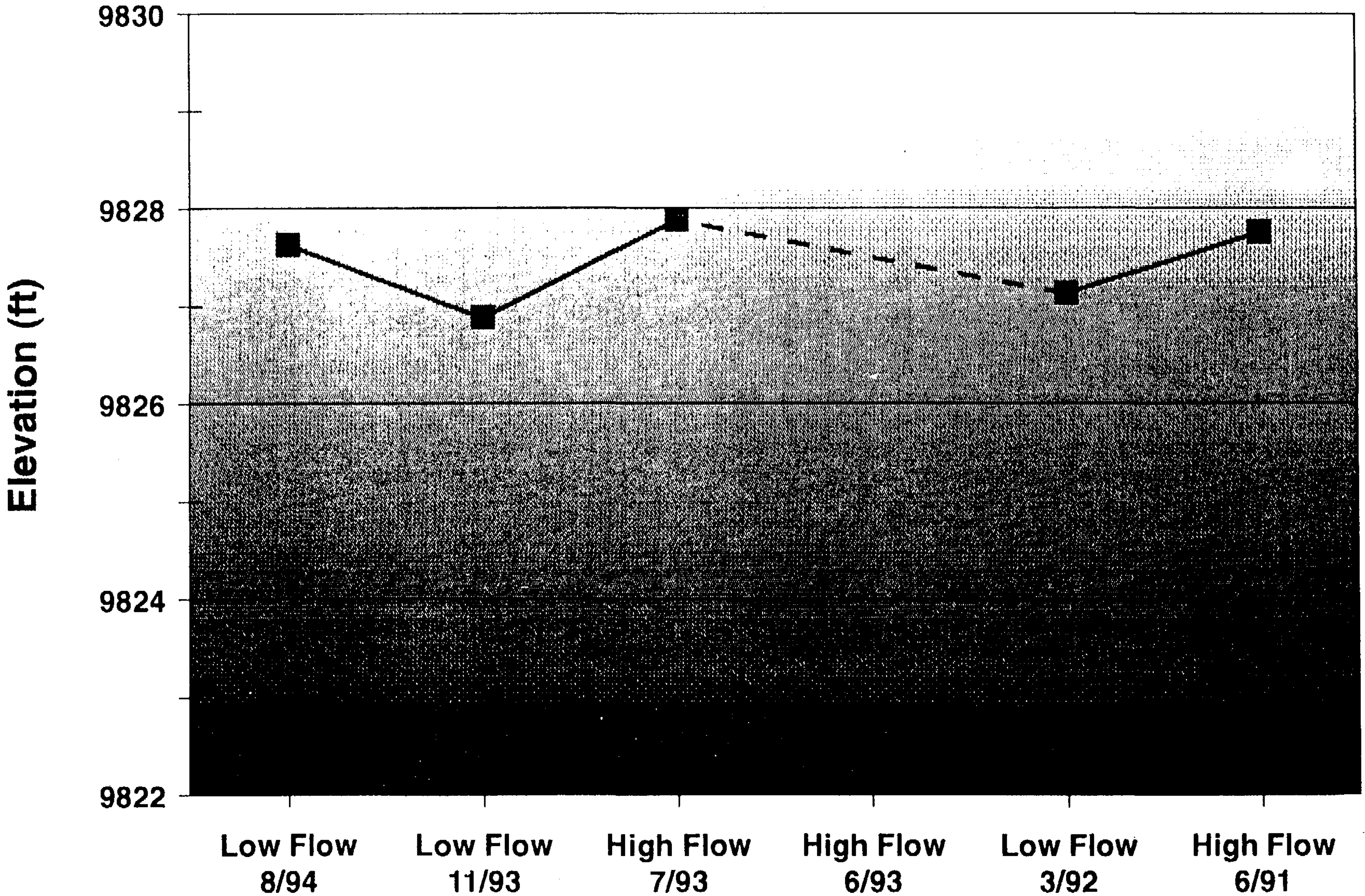
GROUND-WATER LEVEL
VERSUS
TIME
FOR
ALLUVIAL WELL #1
NORTH OF FRENCH GULCH ROAD

FIGURE 22

GROUND-WATER LEVEL
VERSUS
TIME
FOR
ALLUVIAL WELL #7
SOUTH OF FRENCH GULCH ROAD

French Gulch

# Monitoring Well 7



potentiometric surface suggests that the original French Gulch stream channel prior to diversions caused by mining activity is behaving as a line sink south and west of the mine and mill site. This sink explains the lack of seasonal water level variation in monitoring wells located south of French Gulch Road (Figure 22). The November 1993 potentiometric map does not have control points south of French Gulch. There was an additional monitoring well (#15) drilled in October of 1994 east of the Country Boy Mine that has not been incorporated into this study. There is evidence that French Creek east of the 1992 stream diversion is losing water to the alluvial aquifer. The monitoring well #9 SWL during low flow peroids is over 10 feet lower than the stream level which is only 30 feet away. This hydraulic gradient may change during high flow periods switching French Gulch to a gaining stream in this section. Monitoring well #9 does not have SWL measurments during high flow or spring runoff periods (Table X). Local sections of French Gulch may lose or gain depending on the hydraulic gradient between the stream and ground-water aquifers. It is possible that a similar line sink that is indicated north of French Gulch on the November 1993 potentiometric map (Figure 20) may exist on the south side of French Gulch. The surface water quality of French Gulch in the study area is good (SAIC, 1994) and may be due to the losing nature of this section (Figure 2, Table II). Immediately west of the study area and down valley from known seeps with highly metal contaminated waters French Gulch could be experiencing a net gain from ground-water inflow. Surface water quality in this section of French Gulch has much higher metal concentrations (Figure 2, Table II).

Ground-water velocities in the alluvium are estimated to range from 3 to 22 ft/day while the shale ground waters range from 2 to 12 ft/day. These velocities are based on the observed hydraulic gradient, typical porosity values for alluvium and shale, and horizontal hydraulic conductivities derived from the aquifer tests. Metal contaminated ground-water from the mine workings and/or alluvial aquifer could be recharging the shale aquifer resulting in metal plumes in the shale ground-waters. If there is vertical upward movement of ground-water at some time, metal plumes from the shale aquifer that flow into the alluvial aquifer would probably undergo increased dispersion and dilution. This is postulated by assuming that the vertical hydraulic conductivities for the alluvial aquifer are one to two magnitudes greater than the shale aquifer and the alluvium also has higher horizontal hydraulic conductivities and ground-water velocities than the shale aquifer. Recharging the shale aquifer from the mine workings and alluvium or vertical ground-water movement into the alluvial aquifer is probably a function of flow conditions (high & low) and the local hydraulic gradients between the mine workings, the shale aquifer, and the alluvial aquifer. These conditions are dynamic and can change during the year or locally within the valley.

## DISCUSSION

The mine workings, fractured shale bedrock, and alluvium are essentially behaving as one common aquifer. This is supported by the aquifer testing and similar water chemistry. The difference between their ground-water flow characteristics is due to physical properties and local hydraulic gradients. The alluvium horizontal hydraulic conductivity is approximately five to six times greater than the fractured shale bedrock. The vertical and horizontal hydraulic conductivity of the fractured shale bedrock are much higher than typical unfractured shale. Ground-water velocities in the alluvial aquifer are most likely 1 to 2 orders of magnitude greater than the shale aquifer.

The ground-water chemistry data indicates that major metal loading into French Creek originates from the mine and mill site with the fractured shale bedrock in the area containing the highest measured metals contamination (Figures 7 through 9). It is assumed that the majority of metals contamination in the shale is from the mine workings (based on the highly metal contaminated nature of the mine waters), although significant metal loadings could naturally be originating from the highly mineralized fractured shale and/or leaching from the surface mine wastes and roaster fines. The surface leaching is supported by higher metals contamination in the upper alluvium in wells #8, #7, and #6. The unknown degree of downward vertical gradients, if any, within the alluvial aquifer makes it difficult to access the contribution of metal pollution from surface leaching. The relative distribution of iron, zinc, cadmium and other metal concentrations in the ground waters below the mill and mine site to French Gulch demonstrate the potential complexity of chemical reactions during their transport. This study has not addressed possible ground-water chemical reactions, but there are some inferences that can be made.

The higher iron concentrations in the alluvial ground waters are associated with the mill tailings south of French Gulch Road (Figure 10). The high ground-water zinc and cadmium concentrations occur in the vicinity of the roaster fines and mine waste dump (Figure 8). The roaster fines are concentrated metal oxides of iron, zinc, lead, and other metals from the milling process while the mill tailings are predominantly iron sulfides and waste rock void of the zinc, lead, silver, and other ores. Large volumes of fairly oxidized ground waters have been flowing through the valley and possibly leaching the iron sulfides associated with the mill tailings. This may account for the high iron concentrations in the ground-water monitoring wells in the vicinity of the mill tailings. The decrease in all the metal concentrations down gradient from the mill tailings may be due to oxidization of the metals forming colloidal hydroxy polymers that will eventually produce precipitates (Manahan, 1991) and dilution from uncontaminated upper valley ground-waters. The creek, springs, and seeps west of the study area contain red water and have bed surfaces covered with "yellowboy", an amorphous, semigelatinous iron hydroxide. An orange sluge was also observed precipitated on the walls of well no.2 in the tailings disposal area (SAIC, 1994). In addition, high iron concentrations may be causing the other metals to be absorb to sediments. The source of the loading of zinc, cadmium, and other metals in the vicinity of the mine and mill site remain difficult to access because vertical gradients between the mine workings, fractured shale bedrock, and alluvium waters can only be postulated. The large fluctuation in seasonal water levels produces the potential of leaching and mobilizing metals in the alluvium, mine waste dump, and roaster fines. The higher alluvium ground-water temperatures in the mine and mill site area suggests that at some time there has been influx from deeper ground-water, possibly contaminated mine and shale waters, and an upward vertical gradient. Head differences between the mine, shale, and alluvium in the area of the constant discharge aquifer tests suggests that the shale aquifer may act as a sink for the mine and alluvial waters. The potentiometric surface shows that ground-water flow is from the mine and mill site into French Gulch valley (Figure 20).

It is possible that contaminated mine and alluvium waters are flowing through the fractured shale bedrock in a direction indicated by the potentiometric surface map and discharging down gradient where the bedrock outcrops. A seep west of the study area and near alluvial well #7 is associated with the contact between the alluvium and shale bedrock as mapped by Lovering (1934). Surface water sampling last August measured an electrical conductivity from this seep of 1800 umhos/cm. This conductivity is similar to the metal contaminated ground waters at the mine and mill site and is not representative of the alluvium water at well #7 which has conductivities less than 600 umhos/cm (Figure 7). If the seep water is originating from the fractured shale bedrock, major metal loading into French Creek would most likely be from the the fractured shale bedrock in the vicinity of the W-O mine and mill site.

There are several additional evaluations that could be initiated to address the interpretations discussed in this report. Monitoring of static water levels, especially during high flow periods, should be routinely conducted to access potential seasonal changes in vertical and horizontal ground-water movement. Surveyed stage recording stations positioned along French Creek will aid the mapping of the water table and determine losing and gaining reaches along the creek. Stage recorders should also be installed in the mine pool. Additional shale monitoring wells should be drilled in the vicinity of alluvial well #7 and the mine and mill site. An alluvial monitoring well needs to be drilled south of French Creek. The chemistry of the shale waters should be compared with the alluvial and seep waters. All waters should be compared with the water chemistry of upgradient uncontaminated domestic water wells. Geophysical surveys should be run on the new wells to evaluate vertical ground-water movement. These wells can also be incorporated into future tracer surveys that would attempt to track contaminant movement from the mine workings, fractured shale bedrock, alluvial aquifer, seeps, and French Creek. Leaching tests should also be conducted on the mill tailings, roaster fines, and mine waste rock to determine their potential for metal loading. To better understand the fate of metals in the system detailed surface and ground-water chemistry should be studied in terms of speciation, complexation, solubilities, redox reactions, ion exchange and other potential aquatic chemical reactions. Ultimately, metal loading and mass balance evaluations need to be addressed. Detailed underground mine maps need to be compiled for volumetric and mine water chemical analyses to accomplish any metal loading and mass balance evaluations.

# SUMMARY AND CONCLUSIONS

The aquifer tests, ground-water chemistry, and geology indicated that the Wellington-Oro mine workings, the fractured shale bedrock, and the alluvial aquifer are in hydraulic communication. The mapping of chemical parameters and metal concentrations showed the major source of metals pollution is located in the vicinity of the mine and mill site north of French Gulch Road. It is possible that a large portion of metal transport is through the mine workings and fractured shale bedrock to French Gulch. Significant metal loading into French Gulch may be occurring from the discharge of contaminated water west of the study area from springs and seeps associated with the surface exposure of the bedrock with the major pathway for metals being the ground-water associated with the fractured and faulted shale bedrock. Mapping of metal concentrations in the alluvial aquifer suggests that oxidation of iron sulfides are precipitating iron and other metals. The high iron concentrations can also be responsible for the absorption of other metals. This oxidation process could be preventing the alluvial aquifer from being a major source and transport mechanism of heavy metals to French Creek. The contribution of surface leaching of metals from the mine waste rock, roaster fines, and mill tailings to the ground-water and French Gulch needs additional investigation.

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# VOLUME 2

# APPENDIX

## GROUND-WATER HYDROLOGY CHARACTERIZATION

## FRENCH GULCH MINE POOL

## BRECKENRIDGE, COLORADO

April 1995

Prepared for:

U.S. Environmental Protection Agency
Region VIII

Prepared by:

Arthur M. Morrissey
Consulting Geologist
721 S. Moline St.
Aurora, Colorado 80012

# APPENDIX

A WELL COMPLETION DIAGRAMS AND LOGS

B BASE MAP STUDY AREA

C GEOLOGIC CROSS SECTIONS

D GROUND-WATER CHEMISTRY

E AQTESOLV CURVE-MATCHING FOR SLUG TESTS

F CONSTANT DISCHARGE TEST DATA & PLOTS

G STATIC GROUND-WATER LEVELS VS TIME PLOTS

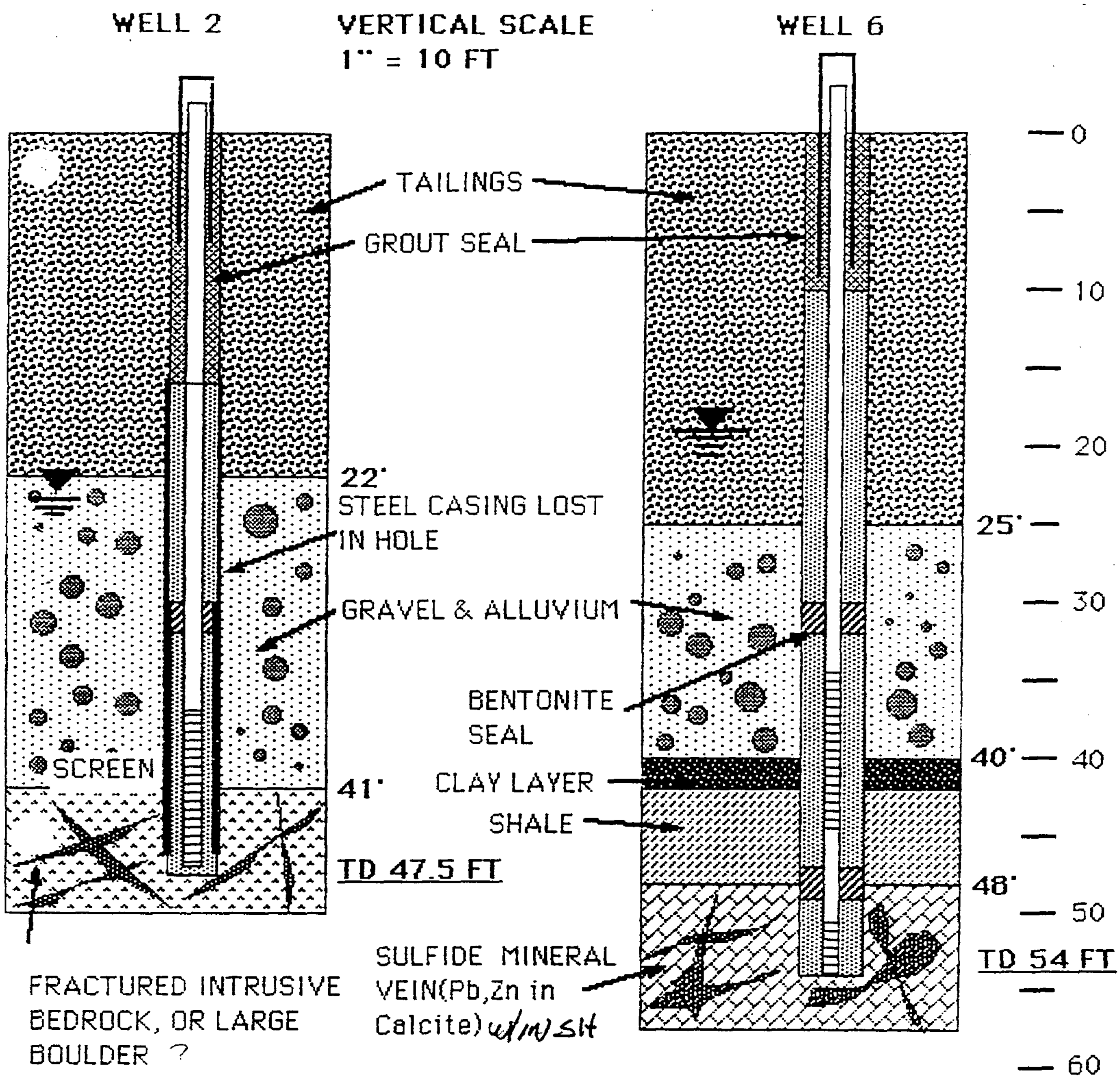
H POTENTIOMETRIC SURFACE MAPPING

# APPENDIX
# A

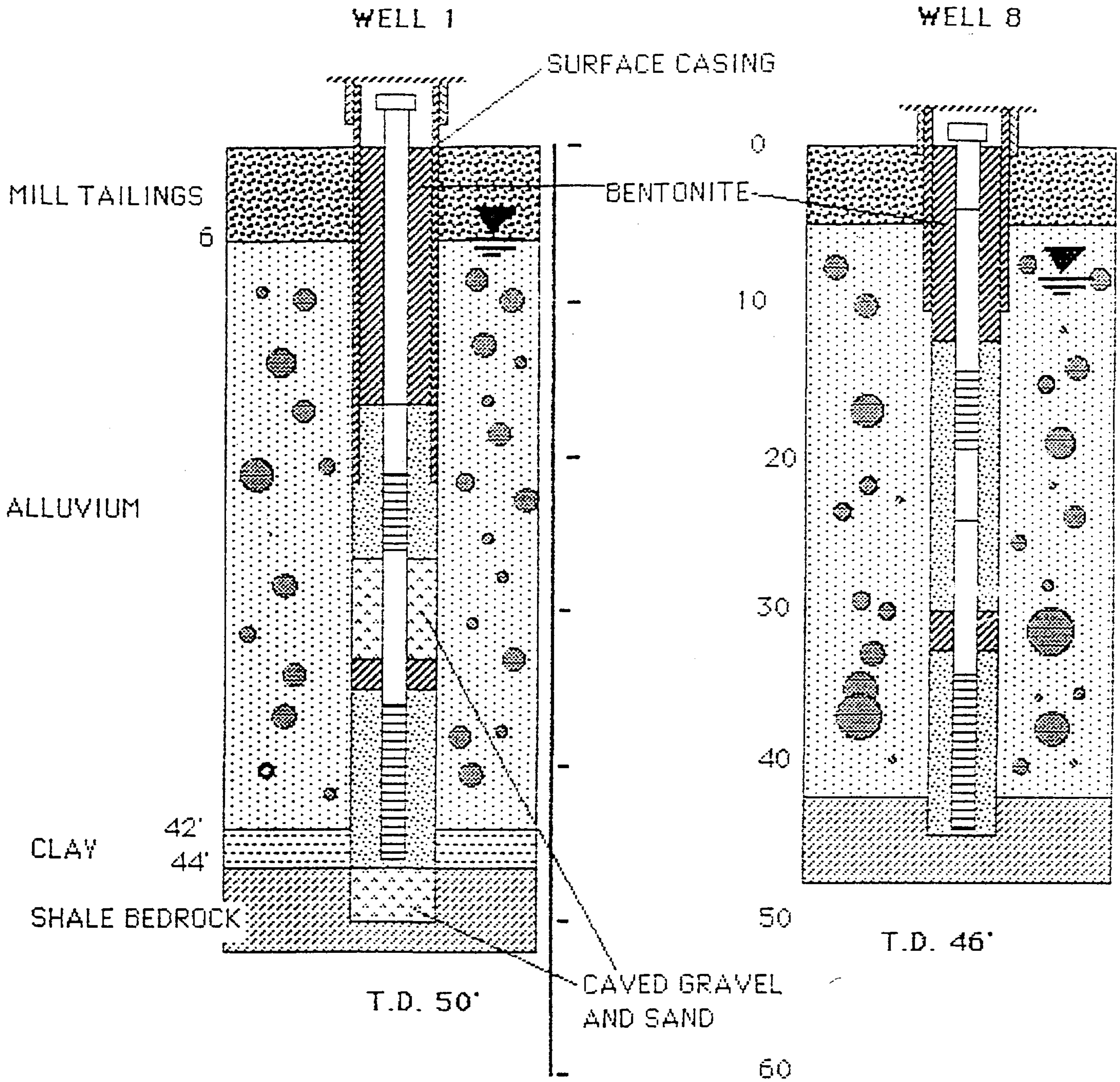
## WELL COMPLETION DIAGRAMS AND LOGS

### FRENCH GULCH MONITORING WELLS

#1
#8
#5
#4
#2
#6
#3
#7
#9
#11
#13
#14
#15
#16
#17
#18
MINE RELIEF WELL #3

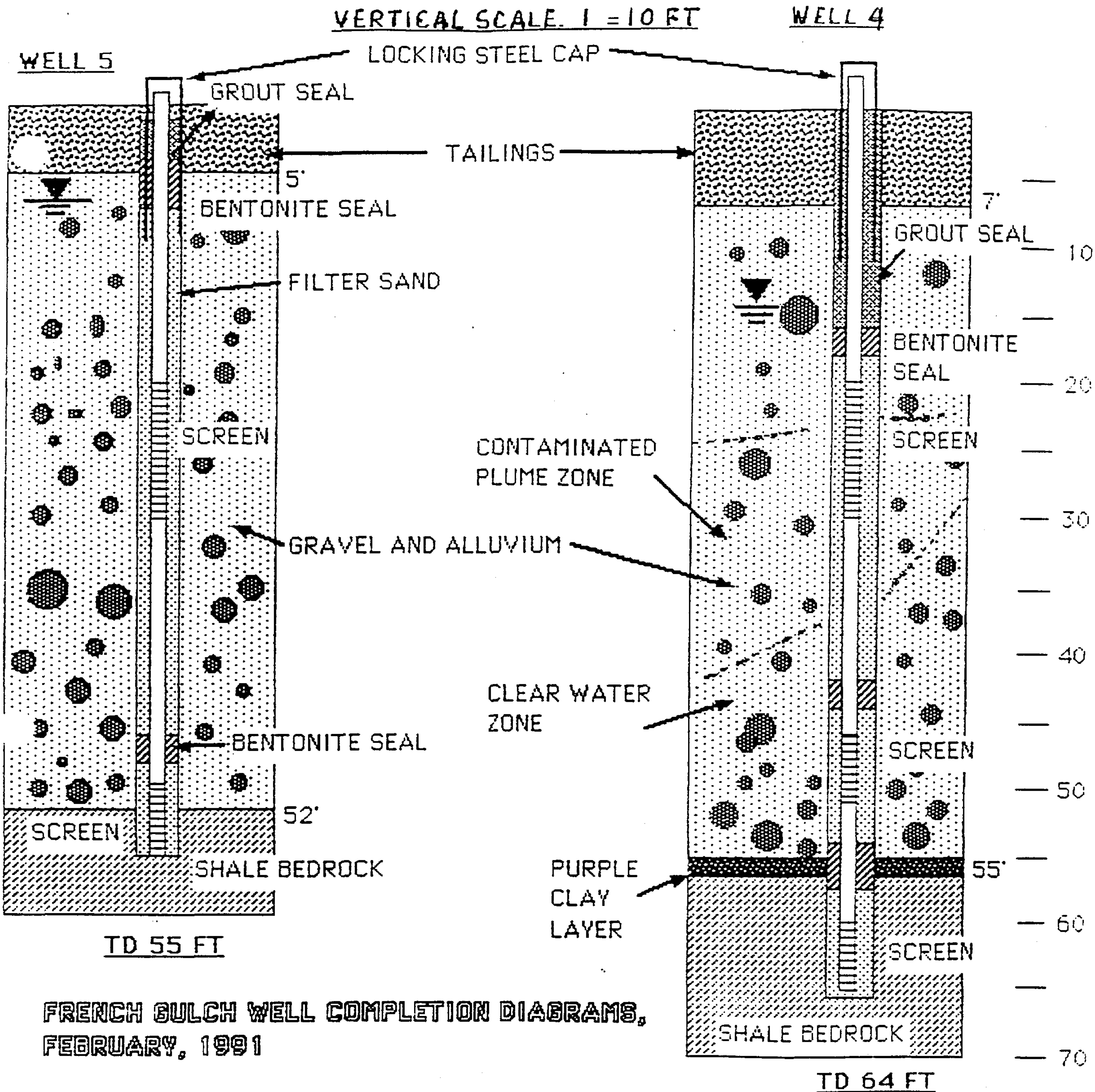



FRENCH GULCH WELL COMPLETION DIAGRAMS,
FEBRUARY 1991

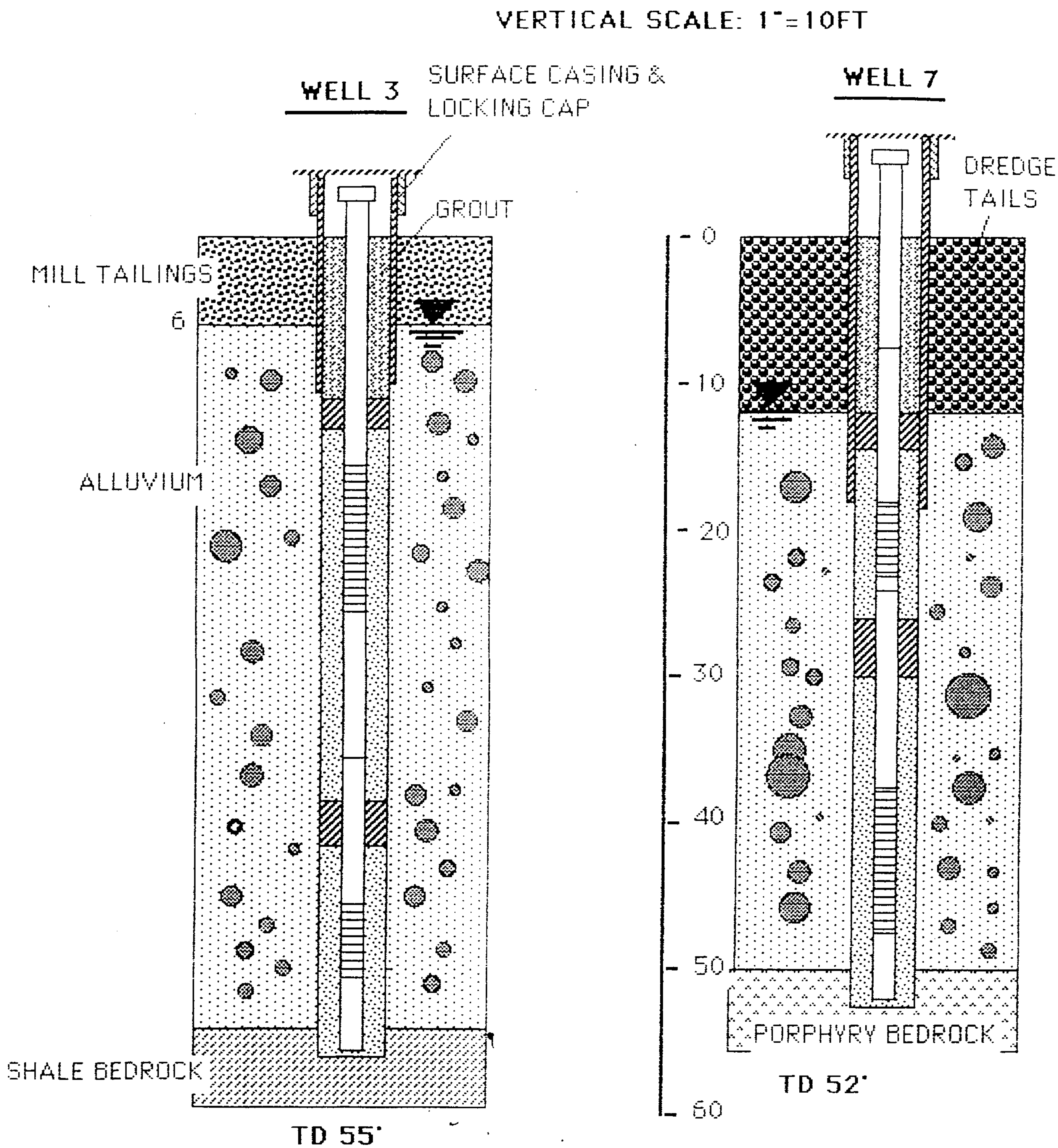



**FRENCH GULCH WELL COMPLETION DIAGRAMS, JUNE 1991**

WATER LEVELS AS OF 6/12/91




FRENCH GULCH WELL COMPLETION DIAGRAMS, FEBRUARY, 1991




**FRENCH GULCH WELL COMPLETION DIAGRAMS, JUNE, 1991**

**WATER LEVELS AS OF 6/12/91**

# COLORADO GEOLOGICAL SURVEY
## ROCK CORE LOG

| | |
|---|---|
| Project | FRENCH GULCH/ORO |
| Location | WELLINGTON/ORO MINE |
| Drilling Co. | GOLDEN DRILLING |
| Driller | Wm. MATTHEWS |
| Surface Elev. | 9,900' |
| Hole Depth | 54.5' |
| Boring No. | 9 |
| Inclination from Horiz. | 90° |
| Bearing | N/A |
| Job No. | |
| WELL Casing Used | 2" PVC |
| Core Size | H (3½) |
| Sheet | 1 of 1 |
| Drill | 7/13 to 7-14 |
| Rig | CANADIAN BOYLES * |
| Geologist | B. STOVER |
| Log Date | 7/13 |

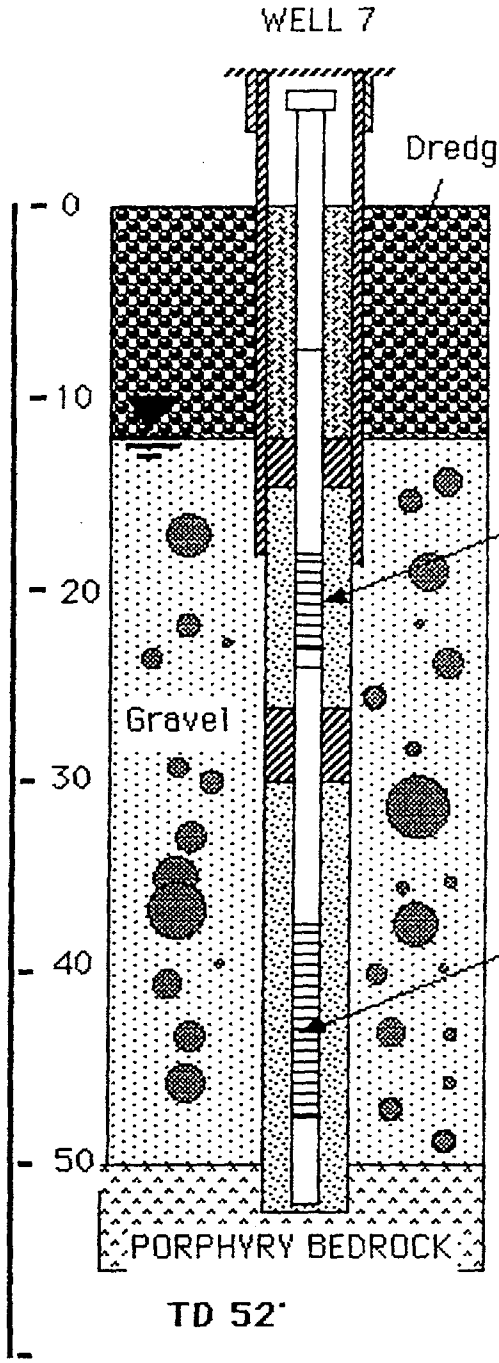
**Surface Description:** ON S. SIDE OF FR. GULCH ROAD ACROSS FROM MAIN DUMP @ WELLINGTON MILL SITE.

**Logging Conditions:** CLEAR, SUNNY, NICE
OA / WIRELINE CORE *

| Formation | % Water Loss | Rock Color | Depth Scale | Geologic Description | Remarks (trace min., samp., stab. water lev., casing, etc.) | Well | Core Recov. % |
|---|---|---|---|---|---|---|---|
| DREDGE TAILINGS | 100 | | 0 | 4" SOIL; GRAVEL, COBBLES, [DREDGE TAILS]. | MIXED LITHOLOGY GRAVELS AND COBBLES. | | 10% |
| | | | 5 | | | | 10% |
| | | | 10 | DREDGE ROCK 0-17' | 0-17 FL. | 10 | |
| | | 17' | 15 | 17-33' | | | |
| FINE GRAVEL & ALLUVIUM | | | 20 | ALLUVIUM; SAND, SILTS CLAYS AND GRAVELS, NOT DISTURBED BY DREDGING, BEDDED ALLUVIUM, ONLY AN OCCASIONAL LARGE COBBLE. | UNDISTURBED 17- ALLUVIUM | 10 | 25% |
| | | | 25 | 33'-41' BOULDERS, MIXED LITHOLOGY, Tqm, Kqcuartzite ~2' THICK. SOME Fe & Mn STAINING | STARTING TO PICK UP SHALE FRAGS. @ 30'. | 10 | |
| BOULDERY ALLUVIUM | | | 30–40 | | CLAY FILLED FRACTURE @ 34'. PYROLUSITE DENDRITES & Fe STAINS ON JOINTS IN BOULDERS @ 40' | 10 | 75% |
| | | | 40–50 | 41-52 NO RECOVERY - [POSSIBLY FINE SILT, SANDS, CLAYS WASHED AWAY (?)] NO - PROBABLE GRAVELS/BOULDERS; NO RECOVERY - CORE BARREL NOT LATCHED. 51-52 - GRAY CLAY - ROCK FLOUR (?) | CORE BARREL NOT LATCHING - CORE RIDING ... CASING | WELL SCREEN 10 | 0% |
| CLAY | | | 52 | 52-54 SHALE BEDROCK, BLACK, WELL INDURATED, PYRITIC. | DRILLED OUT 18" OF CORE NOT PICKED UP IN BARREL w/ SMALL ROD & ROLLER BIT | | |
| Kp | | | 55 | TD 54.5 ft. | | 56½ ft OF PVC | |
| TD 54.5 | | | | | 56½ PVC 10' SCREEN | | |

Rock Quality Parameters: R.Q.D. %, Core Recov. %, Decomposition, Strength, Fracturing
Columns: Formation, Graphic Log, % Water Loss, Bedding ∡, Rock Color, Depth Scale, Joints ∡, Well

WATER QUALITY DATA, 1991 SEASON




**ug/l**

| | TM 6/12 | FM 6/12 | TM 8/1 | FM* 8/1 |
|---|---|---|---|---|
| Al | 17000 | 110 | --- | --- |
| Cd | 24 | 0.7 | --- | 41 |
| Cu | 150 | <4 | --- | <8 |
| Fe | 57000 | 18000 | --- | 25000 |
| Pb | 700 | <5 | --- | <5 |
| Mn | 9100 | 7800 | --- | --- |
| Ni | 27 | <20 | --- | --- |
| Se | 26 | 11 | --- | --- |
| Ag | 4.0 | <0.2 | --- | --- |
| Zn | 18000 | 12000 | --- | 10000 |

| | TM 6/12 | FM 6/12 | TM 8/1 | FM* 8/1 |
|---|---|---|---|---|
| Al | 4300 | --- | --- | --- |
| Cd | 4.2 | --- | --- | 0.7 |
| Cu | 120 | --- | --- | <8 |
| Fe | 30000 | --- | --- | 26000 |
| Pb | 600 | --- | --- | <5 |
| Mn | 130000 | --- | --- | --- |
| Ni | <40 | --- | --- | --- |
| Se | 16 | --- | --- | --- |
| Ag | 2.0 | --- | --- | --- |
| Zn | 8800 | --- | --- | 11000 |

TM = Total Metals
FM = Filtered Metals

* O-rings suspect, data not reliable

#640407

GOLDEN DRILLING, INC.

Wm E. Matthews

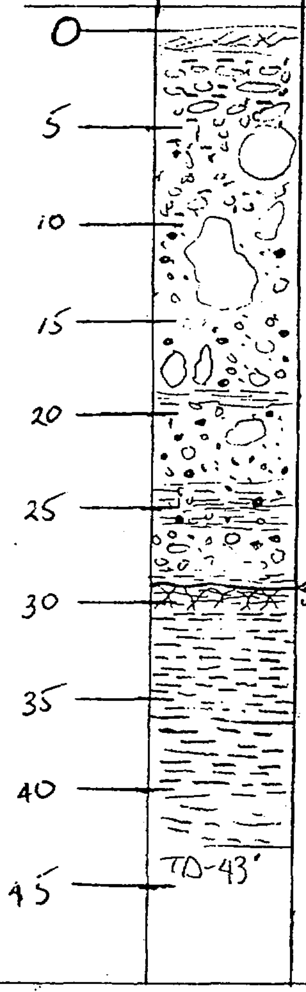
(719) 539-6832

P. O. BOX 387 • SALIDA, COLORADO 81201



HOLE NO 11 LOCATION Wellington Mine, French Gl DATE 10/11/93
OWNER Div. of Mins. & Geology COUNTY Summit STATE CO
DRILLER Wm. Matthews METHOD Air Hammer ADDITIVES
LOGGER B. Stover WATER ENCOUNTERED T.D. 43'
DEVELOPED ✓ YES NO METHOD Hand Bailed
CASING SIZE 2" PLAIN PVC SLOTTED SIZE 0.010 Screen
GRAVEL/SAND/NONE INTERVAL SIZE
bENTONITE SEAL/S
CEMENT INTERVAL
SURFACE PROTECTION SIZE
OTHER

| LITH COL. | SAMPLED BL/IN | WATER LEVEL | NOTES | HOLE DIAG. |
|---|---|---|---|---|




← Top of Shale @ 29' ... Heved in top 1 ft

0-10 FT Colluvium, Slopewash, Mine waste. Admixed shale and intrusive porphyry gravels, and fines

10-29' Alluvium - Gravel, Boulders, and Cobbly Alluvium [Glacial outwash], Zones of clayey sands and pebble gravel

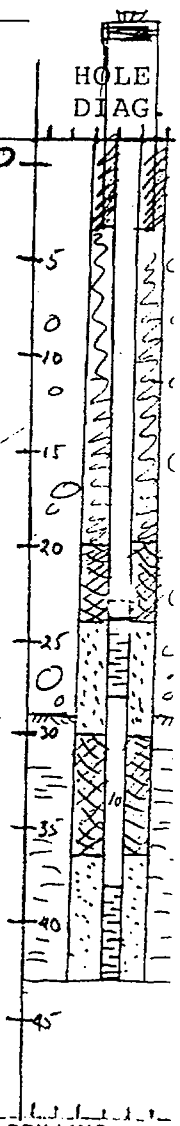
[Blder 13-15½
Clayey Gravel 18-29 Cobbles - 28-29

29' → Soft, Blk marine shale Bedrock; Pyritic, soft, fractured, wet

[Water table on top of shale Bedrock]

Drilled to 43' to allow dual-completion well.

43-38 screen
43-36½ Sand
36½-30 Bent.
30-24 Snd
24-20 Bent
20-4 cuttings



# GOLDEN DRILLING, INC.

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P. O. BOX 387 • SALIDA, COLORADO 81201




HOLE NO FG-12 LOCATION WELLINGTON MINE SITE, FRENCH G. DATE 10/12/93

OWNER DIV. MINS & GEOLOGY COUNTY SUMMIT STATE CO

DRILLER WM MATTHEWS METHOD STRATEX ADDITIVES

LOGGER B. STOVER WATER ENCOUNTERED T.D.

DEVELOPED ✓YES NO METHOD HAND BAILER

CASING PVC SIZE 2" PLAIN PVC SLOTTED PVC SIZE 0.010

GRAVEL/SAND/NONE INTERVAL SIZE

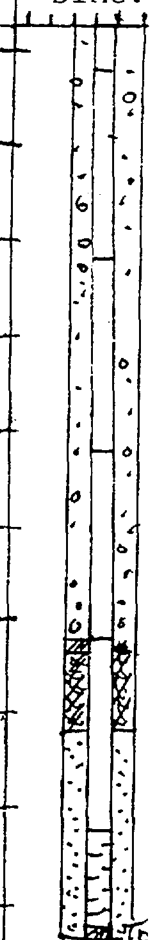
bENTONITE SEAL/S

CEMENT INTERVAL

SURFACE PROTECTION SIZE

OTHER

ORO SHAFT WATER LEVEL @ 85' TODAY

| LITH COL. | SAMPLED BL/IN | WATER LEVEL | NOTES | HOLE DIAG. |
|---|---|---|---|---|
|  | | | |  |
| 0 | | | 0-10 Ft. COLLUVIUM & SLOPEWASH -ROAD BASE MADE FROM ABOVE. COBBLY GRAVELS, SANDS, AND FINES | 0 |
| 5 | | | | |
| 10 | | | 10 — 46 QTZ MONZONITE PORPHYRY - VOLC. INTRUSIVE; HARD, DENSE, HIGHLY FRACTURED; GRAY TO DARK GRAY. | |
| 15 | | | 16'- SOFT, FE OXIDE STAINED FRACTURED, CRUMBLY ZONE TO 19' (FAULT?), SPARSE PYRITE. | |
| 20 | | | | |
| 25 | | | | |
| 30 | | | VERY HARD ZONES | |
| 35 | | | 38-39 - MOISTURE ON DOWN. ~ 1/2 GAL/MIN PRODUCTION | |
| 40 | | | TD 46' IN Tqm | |
| 45 | TD 46' | | 5' SCREEN ON BOTTOM. | |

# GOLDEN DRILLING, INC.

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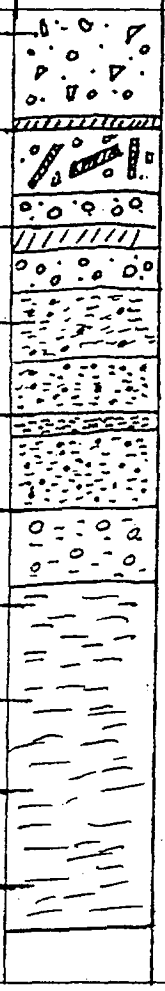
P. O. BOX 387 • SALIDA, COLORADO 81201




HOLE NO FG-13 LOCATION WELLINGTON MINE, FRENCH GULCH DATE 10-13; 10-14-93
OWNER DIVISION of MINERALS + GEOLOGY COUNTY SUMMIT STATE COLO
DRILLER Wm. MATTHEWS METHOD STRATEX ADDITIVES
LOGGER J. NELSON WATER ENCOUNTERED T.D. 47'
DEVELOPED X YES NO METHOD
CASING P.V.C. SIZE 2" PLAIN SLOTTED SIZE
GRAVEL/SAND/NONE INTERVAL SIZE
bENTONITE SEAL/S
CEMENT INTERVAL
SURFACE PROTECTION SIZE
OTHER

| LITH COL. | SAMPLED BL/IN | WATER LEVEL | NOTES | HOLE DIAG. |
|---|---|---|---|---|



0

0-4½' MINE DUMP

5

4½-5' WOOD; MINE TIMBERS ?? OR CRIBBING

MINE DUMP + WOOD MIXED ±70% WOOD (5'-8')

10

CLAY + GRAVEL (w) PYRITE (8'-10')
YELLOW DAMP WOOD 10-11½ (IRON OXIDES)
GRAVEL

15

13½-17 BROWN CLAY (w) SOME GRAVEL

WATER IN HOLE (AM 10-14-93)

20

20-21½ BLK CLAY (w) GRAVEL

21½'-25' DARK BRN to BLACK
BRN CLAY or SHALE (w) FINE GRAVEL >1½"

25

D. BRN CLAYEY GRAVEL (SOME WATER)

30

BLK, CARBONACEOUS SHALE (BEDROCK)

30-32½ BENTONITE PLUG
32½-35½ BENTONITE PLUG

35

SMALL FAULT @ 35'-36'

SAND 35½ to 47'

40

BLK SHALE (BELDEN ?)

45

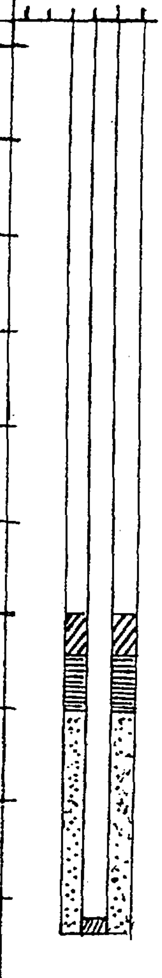
HOLE MAKING ± 2GPM

T.D. 47'

T.D. @ 47 in BELDEN Sh

1' CUTTINGS @ BOTTOM

50



FAULT HOLE

# GOLDEN DRILLING, INC.

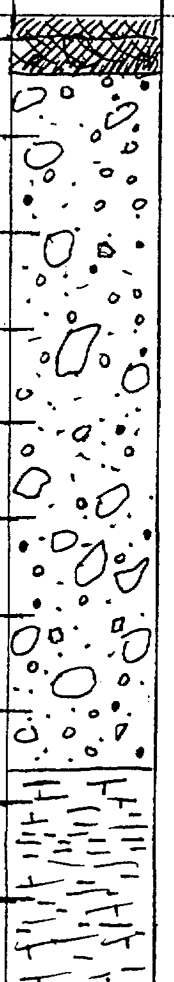
Wm E. Matthews

(719) 539-6832

P. O. BOX 387 • SALIDA, COLORADO 81201



HOLE NO FG-14 LOCATION FRENCH GULCH [11-10 FAULT HOLE] DATE 10/20 TO 10/29
OWNER COLO. DIV. MINS & GEOLOGY COUNTY SUMMIT STATE CO
DRILLER WM. MATTHEWS METHOD STRATEX ADDITIVES FOAM & POLYMER
LOGGER B. STOVER WATER ENCOUNTERED 22' T.D. 277
DEVELOPED ___ YES NO ___ METHOD
CASING ___ SIZE ___ PLAIN ___ SLOTTED ___ SIZE
GRAVEL/SAND/NONE INTERVAL ___ SIZE
bENTONITE SEAL/S
CEMENT INTERVAL
SURFACE PROTECTION STEEL WELLHEAD CASING, 80 FT. SIZE 4"
OTHER

| Depth | LITH COL. | SAMPLED BL/IN | WATER LEVEL | NOTES (START 3:30pm 10/20) | HOLE DIAG. |
|---|---|---|---|---|---|
| 0 |  | | | 0 – 2½ FT – MINE DUMP | 0 |
| 5 | | | | | |
| 10 | | | | | |
| 15 | | | | VALLEY FILL<br>GRAVEL, COBBLES & BOULDERS of<br>LIMESTONE, QUARTZITE, MINOR GRANITE + VOLCANICS? | |
| 20 | | | | | 22' $H_2O$ LEVEL |
| 25 | | | | [AIR DRILLED TO ~40' WHERE TOO MUCH WATER – GO TO WATER CIRCULATION. | |
| 30 | | | | | |
| 35 | | | | BLK SHALE @ 38' – DRY! AT CONTACT (?) | |
| 40 | | | | GAINING WATER FROM 40' ON DOWN TO 65' | |
| 45 | | | | BLK-SHALE – DISSEMINATED PYRITE THROUGHOUT.<br>–Kp MARINE SHALE 14~18 GPM FROM 40 TO 65' | |
| 50 | | | | | |

HOLE NUMBER FG-14 CONTINUED 10/25 PAGE NUMBER 2 of 5

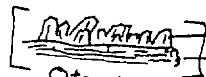
| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCV'Y | GEOLOGY/SOIL DESCRIPTION | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|
| 55 | | STRATEX DOWNHOLE HAMMER | | | | BLK. SHALE – ORO FAULT BLOCK Kp PIERRE SHALE – EXTREMELY PYRITIC | |
| 60 | | | | | | 61' @ 5:00 PM 10-21-93 | |
| 65 | | | | | | WATER RISES TO 20' IN HOLE | |
| 70 | | | | | | CASING TO 70½; AIRHAMMER TO 77~78' – | |
| 75 | | | | | | GRAY—BLACK PYRITIC SHALE, CALCAREOUS, w/ STRINGERS OF WHITE, PYRITIC CALCITE - NUMEROUS "HEALED" FRACTURES w/ CALCITE. FEW GOUGY FRACTURE | |
| 80 | | CORE | 1ST RUN | | | | |
| 85 | | | 2ND RUN | | ~80% | ZONES. ABUNDANT PYRITE THROUGHOUT. | |
| 90 | | | 3RD | 88.0<br>91.2<br>93.2 | | MAKING MORE WATER FROM 90 FT ON (FRACTURED) | |
| 95 | | | 4th | 98.3 | ~80% | CALCAREOUS PYRITIC BLK SHALE/GRAY-BLACK TO 101 FT | |
| 100 | | | 5th | | | | |
| 105 | | | 6TH | 100.6 | 100% | 101 FT→113, TERTIARY INTRUSIVE QTZ MONZONITE PORPHYRY – LIGHT GRAY, PUNKY, ALTERED ABRUPT KNIFE EDGED CONTACT. ALMOST GOUGY, ALTERED TO CLAYS @ 114' FINELY DISSEMINATED PYRITE AND ~~[illegible]~~ GALEANA. FELDSPARS HIGHLY ALTERED ALONG FRACTURES. | |
| 110 | | | | NO2 | QUIT 10/25 | | |
| 115 | | GOUGY | 7TH | 115.0 | ~98% | 119 FT. CARB. BLK SHALE, NO CALCITE STRINGERS TO 131 FT; PYRITE LENSES, SOFT, CARBONACEOUS | |
| 120 | | | 8TH | | | | |

REMARKS

WILL CASE DOWN TO 70', THEN BEGIN CORING ABOVE FAULT ZONE. HQ DOWN TO 78'

(N) ~~[illegible]~~ ON DOWN TO

HOLE NUMBER FG-14 CONTINUED 10/26 PAGE NUMBER 3 of 5

| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCV'Y | GEOLOGY/SOIL DESCRIPTION | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|
| 120<br>125 | Pyrite | 127 2 | | | 80%<br>80% | CARBONACEOUS BLK. PYRITIC SHALE, SOME FRACTURES, ALMOST SOLID PYRITE SEAMS EVERY SO OFTEN. 101' → 131'<br>1/4" THICK PYRITE VEIN @ 128' | |
| 130<br>135 | 2" Fault | 131' – Calcite<br>133 7 – | | | 70% | CALCAREOUS SHALE 131 TO 240 [1/4" THICK CALCITE VEIN AT 132 1/2 FT, PYRITIC] GRAY TO BLACK, CALCITE VEINLETS MORE WATER LOSS AT 135' - NO CIRCULATION AT SURFACE - COMES BACK. VUGS @ 132'. 2" GOUGY FRACTURE @ 139'. HARD. ABDNT. PYRITE THROUGHOUT. | ▼@22' |
| 140<br>145 | Qtz vein<br>1" Gouge | 143 7 | | | | 1/8" Qtz VEIN @ 147 FT - VUGGY - GOOD XTALS. <br>1" GOUGE AT 149'. | |
| 150<br>155 | | 150 2 | | | | CALC. SHALE w/ CALCITE VEINLETS, PYRITE | |
| 160<br>165 | | 160 3<br>166 5 | | | | | |
| 170<br>175 | | 176 · | QUIT 10/26 | | | 1/4" Qtz & CALCITE FILLED FRAC/VUG | |
| 180<br>185 | Qtz Vug | 186 ? | | | | Qtz FILLED VUGS @ 189<br>CALCITE SWIRLS | |
| 190 | | | | | | | |

REMARKS

HOLE NUMBER FG-14 CONTINUED 10/27 PAGE NUMBER 4 of 5

| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCV'Y | GEOLOGY/SOIL DESCRIPTION | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|
| 190 – 195 – 200 | | 193 1, CALCITE LAMS. | | | 100% | CALCAREOUS GRAY—BLACK SHALE; HARD, CALCITE STRINGERS/VEINLETS, PYRITIC; THIN RIP-UP MUD/CALCITE BEDS @ 199 ft. FULL RECOVERY. SOLID-ALMOST NO FRACTURES | WELL COMPLETION DIAGRAM |
| 200 – 205 – 210 | | 202 2 | | | 100% | | |
| 210 – 215 – 220 | | 212 3, FAULT | | | 100% | | |
| 220 – 225 – 230 | | 222 2, 225 5, 229 2 | | | | 2½" CRUSHED, GOUGY ZONE, SLICKS, MVMT INDICATIONS @ 218½' TO 221 FT FRACTURED, BROKEN, POORER RECOVERY 222-225, 225-227. | |
| 230 – 235 – 240 | | 236 3, ALTERED | QUIT 10/27 | | 100% | GOOD RECOVERY AGAIN @ 228<br>ALTERED LIMEY SHALE, BRITTLE, BEDDING LOST, NO CALCITE VEINLETS | |
| 240 – 245 – 250 | | VOLC. INTRUSIVE, 246 5, 250 | 100%, VOLC. 100% | | 100% | 240—243½ FINE GRAINED VOLC. INTRUSIVE; PYRITE & CHALCOPYRITE VEINLETS; RIP-UP BASAL CONTACT W/ SHALE FRAGS, WAVEY, ABRUPT LOWER CONTACT. PYRITIC THROUGHOUT.<br>243-246 3 CALCAREOUS GRAY TO BLACK SHALE W/ CALCITE VEINLETS 246 3-246 5 -2" VOLC INTRUSIVE VEIN | |
| 250 – 255 – 260 | | 255 — HEALED FAULT, CARB SHALE, FAULT ZONE | | | | 246 5 → CALC. BLK. SHALE, HEALED FRACTURE/CRUSHED ZONE @ 249, w THIN GOUGE VEIN, QTZ ON CALCITE VUG. HARDER, NO BEDDING @ 253.' SHALE TURNS CARBONACEOUS AT 256 SMALL CRUSHED FAULT ZONE-HEALED @ 255—255 6<br>FAULT 258 6 TO | PVC |

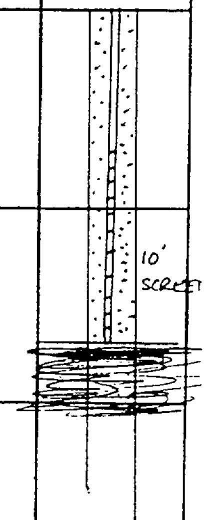
REMARKS

SLICKS/STRESS CUTANS THROUGH CARB SHALE ABOVE FAULT @ 258 6 XXXX

BENTONITE SEAL

SAND FILTERPACK TO 250'

HOLE NUMBER FG-14 CONTINUED 10/28 

| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCV'Y | GEOLOGY / SOIL DESCRIPTION | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|
| ~~260~~ 265 |  | 262½ FAULT ZONE | 11-10 | | ~50% | FAULT, 258½ TO CRUSHED, GOUGY, SOFT, MUDDY, BROKEN CARB. SHALE, SLICKS ON FRAGS, HEAVILY PYRITIZED, WHITE GOUGE SEAM 269 TO 271 |  |
| 270 | | 268½ WHITE GOUGE | SEAM | | | | |
| 275 | | 271½ 275° 278½ TD | QUIT 10/28 | | ~10% | FRACTURED, BROKEN SHALE, GOUGE SEAMS @ 275-277<br>TO 278½ FT IN FAULT ZONE | 10' SCREEN |
| 280 | | | | | | | |
| 285 | | | | | | | |

REMARKS WELL COMPLETION NOTES:

SCREEN ~~278 TO 268'~~ 276, TO 266 (PLASTIC MOVED UP 2 FT WHILE PULLING CASING)

SAND FILTER PACK TO 250'

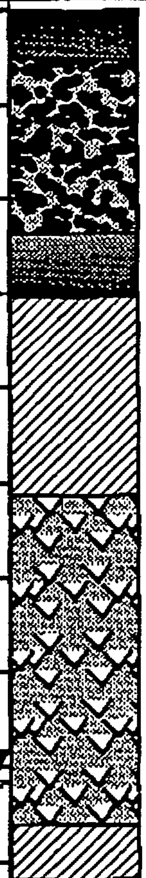
BENTONITE SEAL 250 TO 230' (20')

# Division of Minerals & Geology Drilling Log

PROJECT: French Gulch/FATCAT
LOCATION: Sec 32T6S,R77W
COUNTY: Summit
DRILLING CO. Golden Drilling Inc.

DRILLER Wm. Matthews
RIG TYPE Track Drill #1
METHOD dwnhole hammer
HOLE SIZE 4in.

HOLE No. 15
Collar Elev. 9789
Total Depth 46
Date Started 10/17/94
Date Compl. 10/19/94
Logged By B.Stover

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| 0 |  | 0 - 3' Topsoil |  |
| | | 3 - 12' Sand, gravel, cobbles, alluvium, lt. yellow | |
| 10 | | 12 - 15' Clayey gravel & sand, black to dark gray, damp. | |
| 20 | | 15 - 26' Black shale bedrock, dry,(Pierre Shale) | |
| 30 | | 26 - 43' Light gray intrusive volcanic qtz. monzon--ite porphyry, dry | Bentonite Seal |
| 40 | | | Water level @ 41' |
| | | 43 - 46 Black shale, picking up water from 41' on. | Filter Sand |
| | TD 46 | | |
| 50 | | | |
| 60 | | | |

Post-It™ brand fax transmittal memo 7671 | # of pages ▸ 6

| | |
|---|---|
| To ART MORISSEY | From B. STOVER |
| Co. SNYDER OIL Co | Co. COLO. DMG |
| Dept. | Phone # 866-3567 |
| Fax # 592-8602 | Fax # 832-8106 |

Remarks

# Division of Minerals & Geology Drilling Log

PAGE 1 OF 2

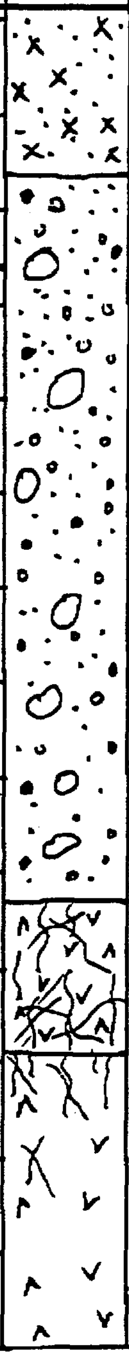
**HOLE No.** 16
**Collar Elev.** 9881.65
**Total Depth** 91

**PROJECT:** FRENCH GULCH/FAT CAT
**Location:** Sec 32 T. 6S R. 77W
**County:** SUMMIT
**Drilling Co.** GOLDEN DRILLING

**Rig Type** TRACK DRILL
**Method** DOWN HOLE/STRATECH.
**Hole Size** 4"

**Date Started** 10/12
**Date Compl.** 10/17
**Logged By** B. STOVER

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| 0 | | 0-8 MINE & MILL TAILINGS, 2" MINUS ORANGE/YELLOW/BRN. | |
| 10 | | 8-46.5 ALLUVIUM & GLACIAL OUTWASH; UNDISTURBED (NOT DREDGED) SAND, GRAVEL COBBLES, BOULDERS. $H_2O$ @ 13'. PROGRESSIVLY WETTER | |
| 20 | | | 2" PVC MONITOR WELL |
| 30 | | | |
| 40 | | | |
| 50 | | 46.5 – 54.5 QTZ. MONZ. PORPHYRY INTRUSIVE, DECOMPOSED, HIGHLY FRACTURED, HVY FE STAINING ON HAMMER & CUTTINGS, LT. YELLOW COLOR WATER | |
| 60 | | 54.5-70 PORPHYRY, FIRM, LESS FE STAIN ON CUTTINGS, 12-15 GPM WATER | 4" CASING SET TO 59' DURING DRILLING |
| 70 | | | |



Remarks

**Division of Minerals & Geology Drilling Log**

PG 1 OF 2

HOLE No. 17
Collar Elev. 9882.13
Total Depth 93

PROJECT: FRENCH GULCH / FAT CAT
Location: Sec 32 T. 6S R. 77W
County: SUMMIT
Drilling Co. GOLDEN / TWIN PEAKS

Rig Type CHI. PNUE. 1650W
Method ROTARY / CASING HAMMER
Hole Size 6"

Date Started 10/18
Date Compl. 10/27
Logged By BKS

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| |  | 0-9 MINE/MILL TAILINGS | |
| 10 | | | |
| | | 9-46 GLACIAL OUTWASH/ALLUVIUM - BOULDER/HARD ZONE @ 35' OR SO | |
| 20 | | | |
| 30 | | | |
| 40 | | | |
| 50 | | 46-54 WEATHERED, SOFT, CRUMBLY, HIGHLY FRACTURED, DECOM-POSED - HOLE WON'T STAND OPEN | |
| 60 | | 55-70 PORPHYRY INTRUSIVE, FIRM, HOLE STANDING OPEN | |
| 70 | | | |

Remarks

# Division of Minerals & Geology Drilling Log

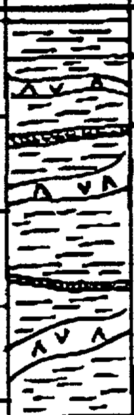


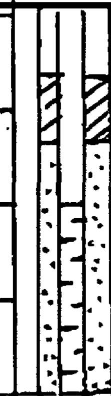
PROJECT: FRENCH GULCH / FAT CAT
Location: Sec 32 T. 6S R. 77W
County: SUMMIT
Drilling Co. GOLDEN DRILLING

Rig Type TRACK
Method STRATITECH.
Hole Size 4"

HOLE No. 16
Collar Elev. 9881.65
Total Depth 91
Date Started 10/12
Date Compl. 10/17
Logged By BKS

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| 70 | | 70-72 BLACK SHALE (Kp) ~ 30 GPM WATER PRODUCTION | 4" STEEL CASING SET TO 59'; BENTONITE SEAL |
| 80 | | 72-91 BLACK SHALE AND INTERLAYERED PORPHYRY INTRUSIVE; 2 SEAMS OF WHITE GOUGE (?) @ 76' & @ 83 (6" THICK SEAMS) | 10 FT SCREEN; 15' FILTER SAND |
| 90 | T.D. 91 | | 91' |
| 100 | | | |





Remarks

# Division of Minerals & Geology Drilling Log

PG 1 OF 1

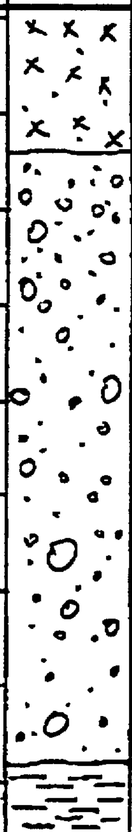
HOLE No. 18
Collar Elev. 9882.98
Total Depth ____

PROJECT: FRENCH GULCH / FAT CAT
Location: Sec 32 T. 6S R. 77W
County: SUMMIT
Drilling Co. GOLDEN DRILLING

Rig Type: CHICAGO PNUEMATIC 1650W
Method: ROTARY w/ CASING DRIVER
Hole Size: 6"

Date Started ____
Date Compl. ____
Logged By ____

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| | | 0-7' MINE/MILL TAILINGS, 2" MINUS YELLOW/BRN, FINE GRND. | 4" PVC |
| 10 | | 7-39 ALLUVIUM, GLACIAL OUTWASH; SND, GRVL, COBBLES, (UNDISTURBED) 30+ GPM WATER PRODUCTION NEAR BEDROCK | CUTTINGS/CAVED HOLE |
| 20 | | | BENTONITE |
| 30 | | | 19-39 FILTER PACK 20 & 10' SCREEN |
| 40 | | 39-43 BLK SHALE BEDROCK | TD |
| | TD 43' | | |
| 50 | | | |



Remarks

4" PVC PUMP TEST WELL

# Division of Minerals & Geology Drilling Log

PG 2 OF 2

HOLE No. 17
Collar Elev. 9882.13
Total Depth 93

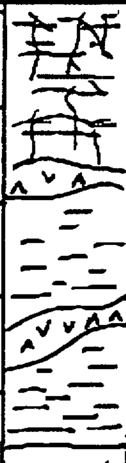
PROJECT: FRENCH GULCH / FAT CAT

Location: Sec____ T.____ R.____
County: ____

Drilling Co. ____

Rig Type ____
Method ____
Hole Size ____

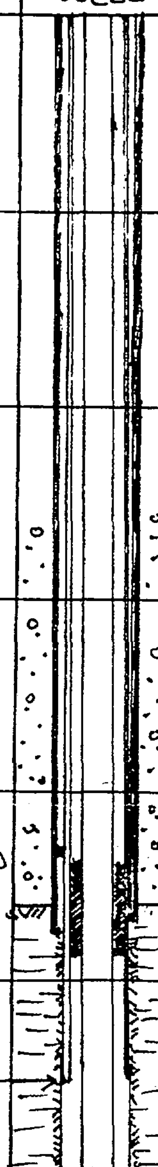
Date Started 10/18
Date Compl. 10/27
Logged By BCS

| DEPTH | Rock Type | Geologic Description | Samples, Drilling Notes Well Completion Diag. |
|---|---|---|---|
| |  | 70 - 82 CRUMBLY, FRACTURED, BLACK SHALE (CONTACT METAMORPH) - HOLE UNSTABLE, WILL NOT STAND OPEN |  73 |
| 80 | | | |
| | | 82 - FIRMING UP, BUT STILL OCC. CLAYEY ZONES. 5" STEEL TAKEN ALL THE WAY TO 93 FT, THEN WITHDRAWN AROUND 4" PVC WELL PIPE. | 20 10' SCREEN |
| 90 | | | |
| | TD. 93' | | TO 93 |
| 100 | | | 4" PVC WELL |

Remarks

EXTREMELY DIFFICULT TO DRILL W/ LARGE SIZED HOLE. BEDROCK WILL NOT STAND OPEN IN MANY PLACES.

| | | | | | |
|---|---|---|---|---|---|
| PROJECT | French Gulch/Ord | LOC. STR | 32-6S-77W | DRILLER | Wm. Matthews |
| HOLE NO. | "Relief Well" | COUNTY | Summit | RIG TYPE | Rotary Schramm Roto-Drill |
| DATE STARTED | 1/13/92 | LAND OWNER | USFS/B&B Mines | HOLE SIZE | 7 7/8" |
| DATE COMPLETED | 1/16/92 | COLLAR EL. | 9885.7 | GWT DEPTH | 10' |
| TOTAL DEPTH | 110 ft | LOGGED BY | BKS | | Rotary w/ Air Circ. |

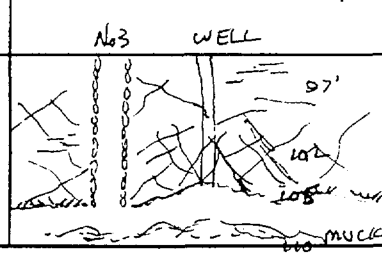
| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCY'Y | GEOLOGY/SOIL DESCRIPTION | ~~SAMPLE~~ ~~TYPE~~ WELL |
|---|---|---|---|---|---|---|---|
| 0–10 |  | | | | | 0 - 45 ft Glacial outwash alluvium; sndy gravel, cobbles, bldrs, water |  |
| 10 | | ▼ | | | | table @ 10 ft. | |
| 20 | | | | | | 8" steel surface casing to 46' 6" PVC to 55' Boot packer @ 43' | |
| 30 | | | | | | | |
| 40 | | | | | | 45' — Black shale bedrock, mineralized w/pyrite, galena, calcite, hard brittle (Kp) metamorphosed Pierre shale, pyritized, occassional 2mm pyrite cubes, weathered at top | |
| 50 | | | | | | 6" PVC to 55' | |
| 60 | | | | | | | |

REMARKS Relief well PVC could not be set to mine level due to unstable hole. Bedrock/alluvium contact sealed; mine can drain through washed rock column set to mine roof from 68' to 105.' Rock above mine is cavey, unstable/subsided, and is saturated by mine pool -

4" PVC to 68'
Boot packer @ 48'
Bentonite seal 48-43'

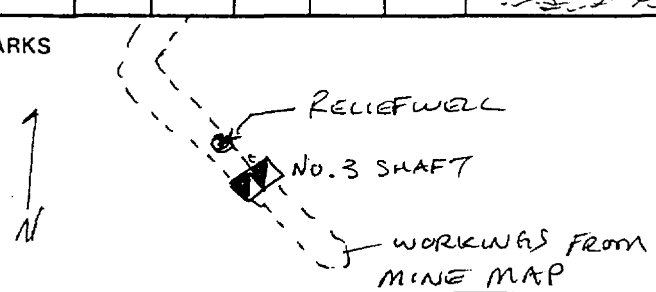
HOLE NUMBER "Relief Well CONTINUED 1-15-92 PAGE NUMBER ______

| DEPTH | ROCK TYPE | RQD % | BLOW COUNT 12" | BOX NO. | % RCV'Y | GEOLOGY / SOIL DESCRIPTION | SAMPLE TYPE |
|---|---|---|---|---|---|---|---|
| 65 – 70 | | | | | | FRACTURED, MINERALIZED SHALE BEDROCK, 4" PVC TO 68' → | |
| 70 – 80 | | | | | | WASHED 3/4" ROCK 68' → 110' | |
| 80 – 90 | | | | | | MINERALIZED CALCITE VEIN 92 | |
| 90 – 100 | | FRACTURES @ 97'- LOST AIR CIRCULATION... | | | | LOST AIR CIRCULATION @ 97'- AIR LIFTING WATER OUT OPEN No. 3 SHAFT - WATER IS ORANGE FLOWING OUT SHAFT. NO VOIDS - CIRC. LOSS PROB THROUGH | |
| 100 – 110 | | LOTS OF CIRCULATION<br>-3' VOID<br>-MUCK<br>STEEL RAILS (?) | | | | FRACTURES TO SHAFT. HOLE MAKING ORANGE WATER @ 102' - (MINE POOL ??) TOP OF MINE ROOF @ 105'. SOFT RUBBLE TO 109/110 FT. - HIT STEEL @ 110'.... | MUCK |
| 110 | TD. | | | | | TWISTED OFF 7 7/8 BIT AND 5' SUB ON STEEL RAILS (?) ON MINE FLOOR, DESTROYED 20' JOINT.<br>TD 110'<br>MINE POOL @ 102' | MINE FLOOR |




BEDROCK HEAVILY FRACTURED BELOW 97' - STOPING (?) OR CAVED/SUBSIDED INTO MINE (?)

REMARKS




NOTE: WELL IS CAVED, UNSTABLE BELOW 90'. RELIEF FOR MINE TO DRAIN STABILIZED w/ 3/4" WASHED ROCK FROM 105 TO 68'. BEDROCK/ALLUVIUM SEALED OFF 43-48' INSIDE 6" PVC.

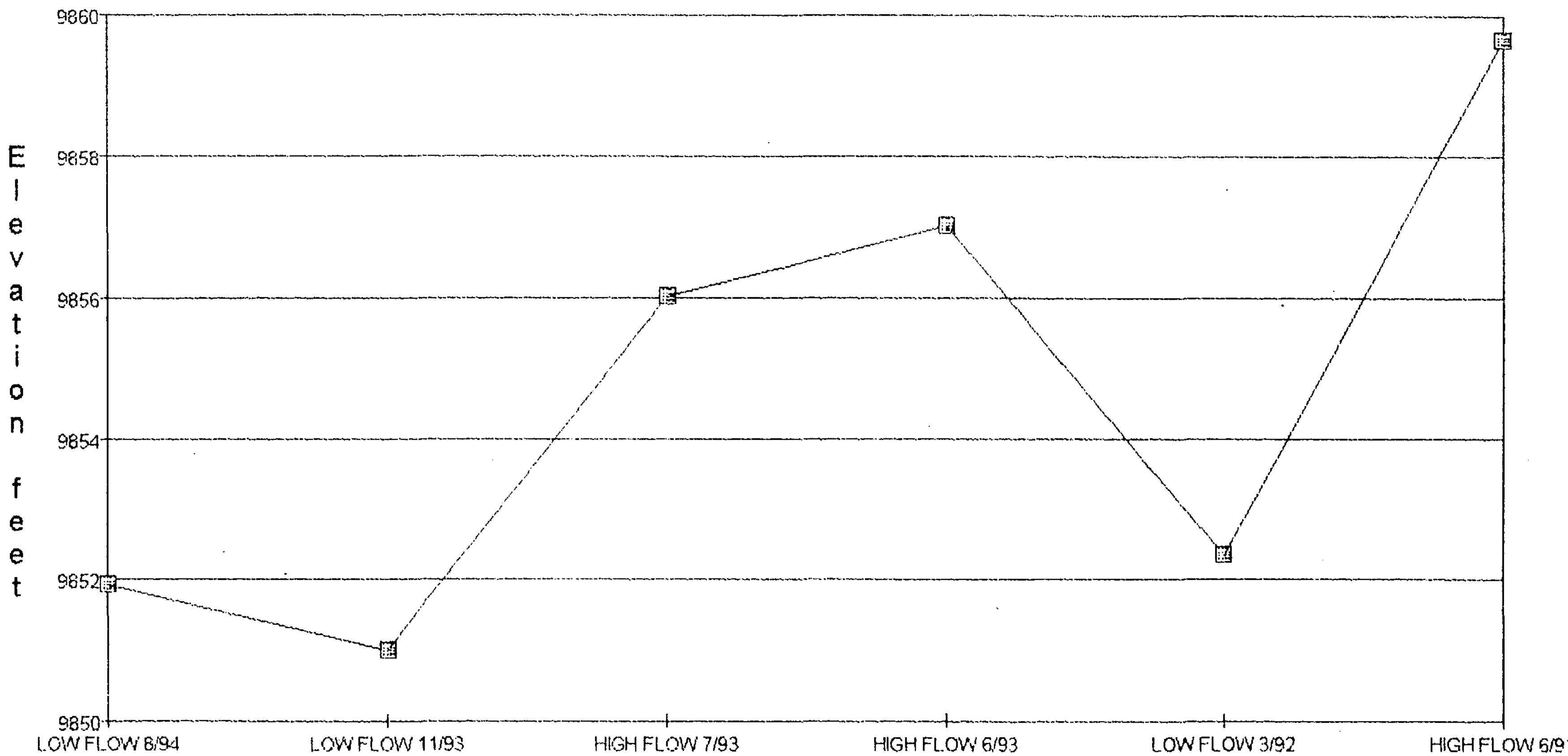
# APPENDIX
# G

## STATIC GROUND-WATER LEVELS VERSUS TIME

### FRENCH GULCH MONITORING WELLS

#2
#3
#4
#5
#6
#8
#3 MINE RELIEF WELL & #1

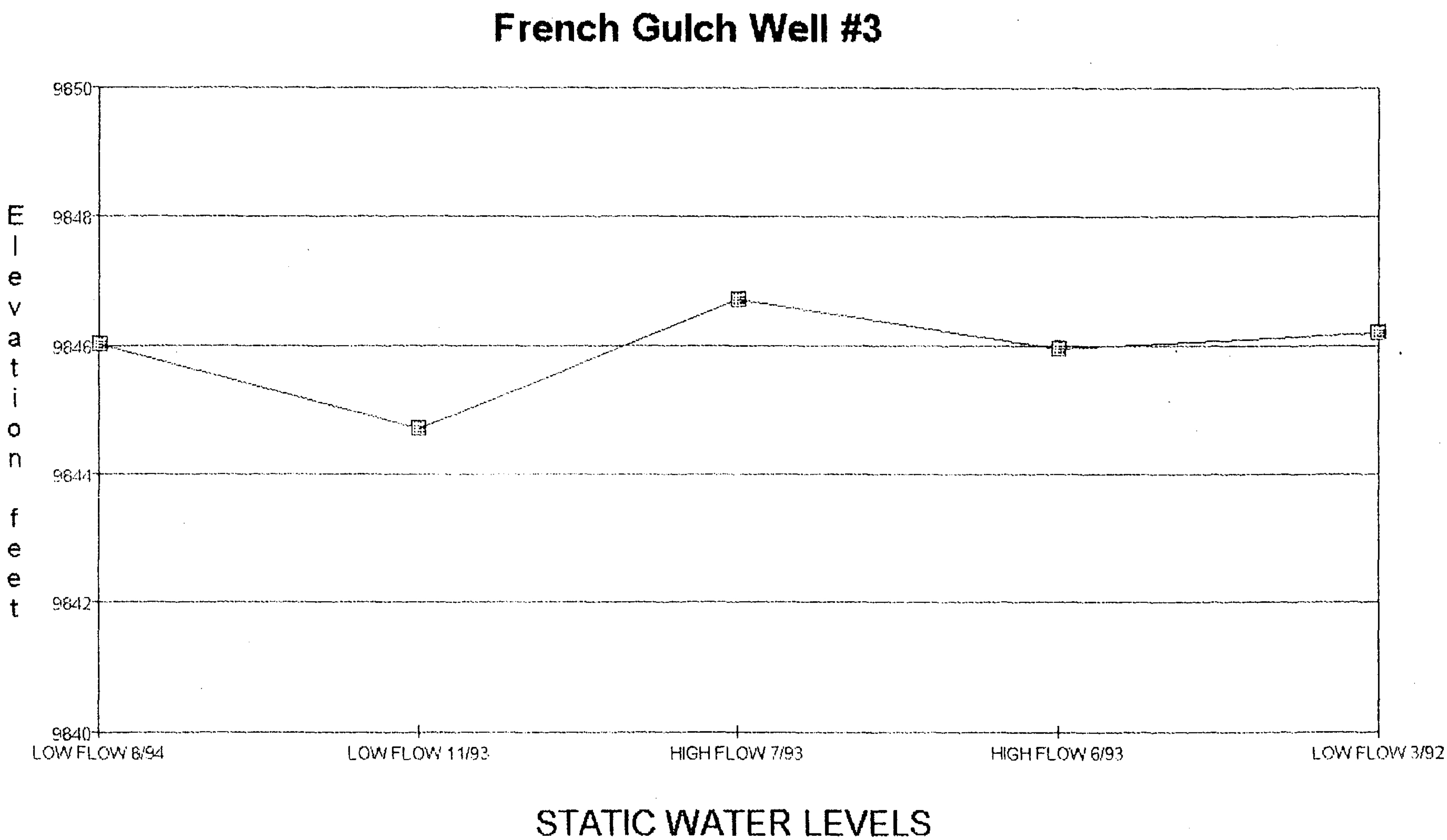
# French Gulch Well #2




STATIC WATER LEVELS

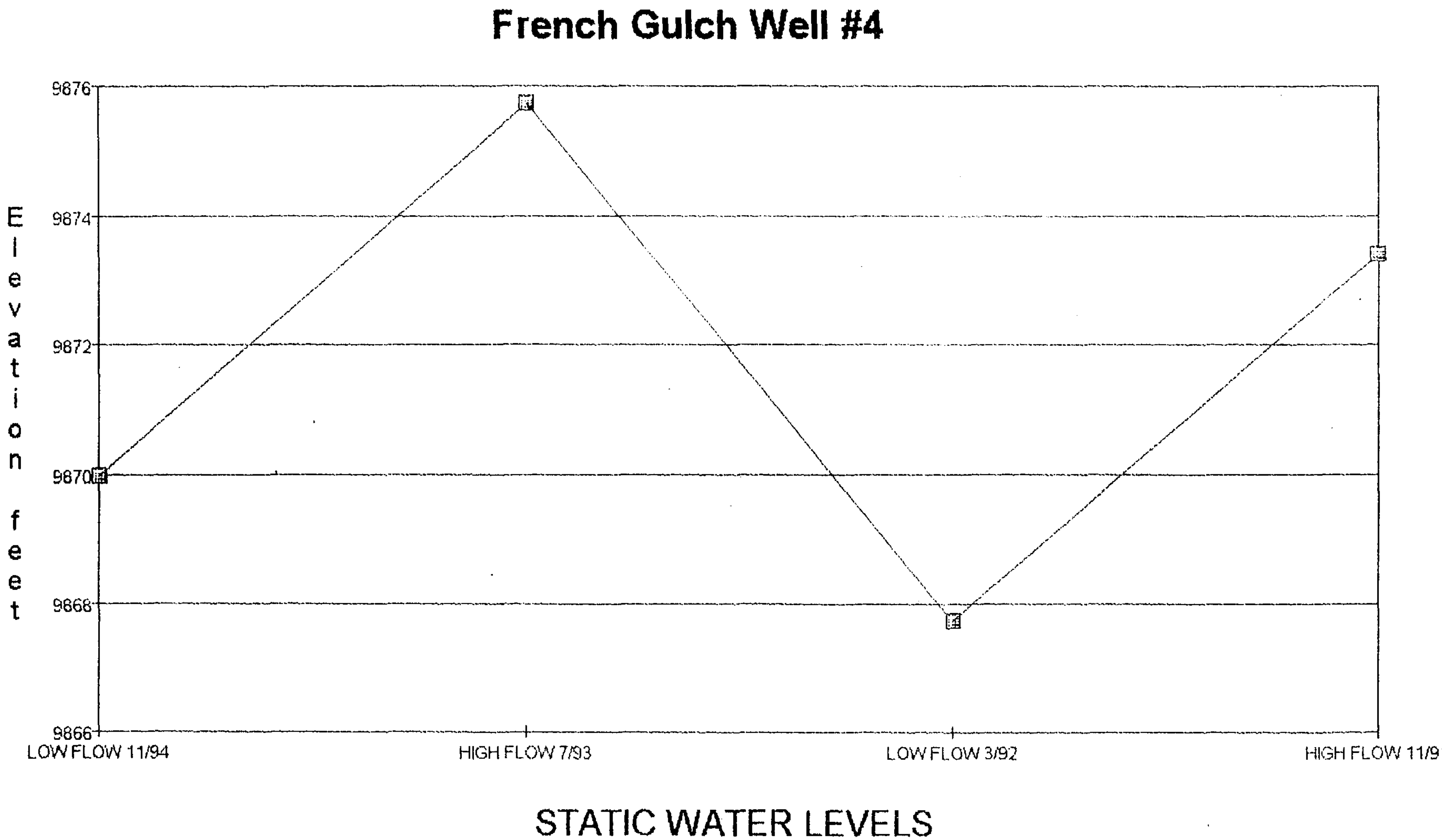
6

6



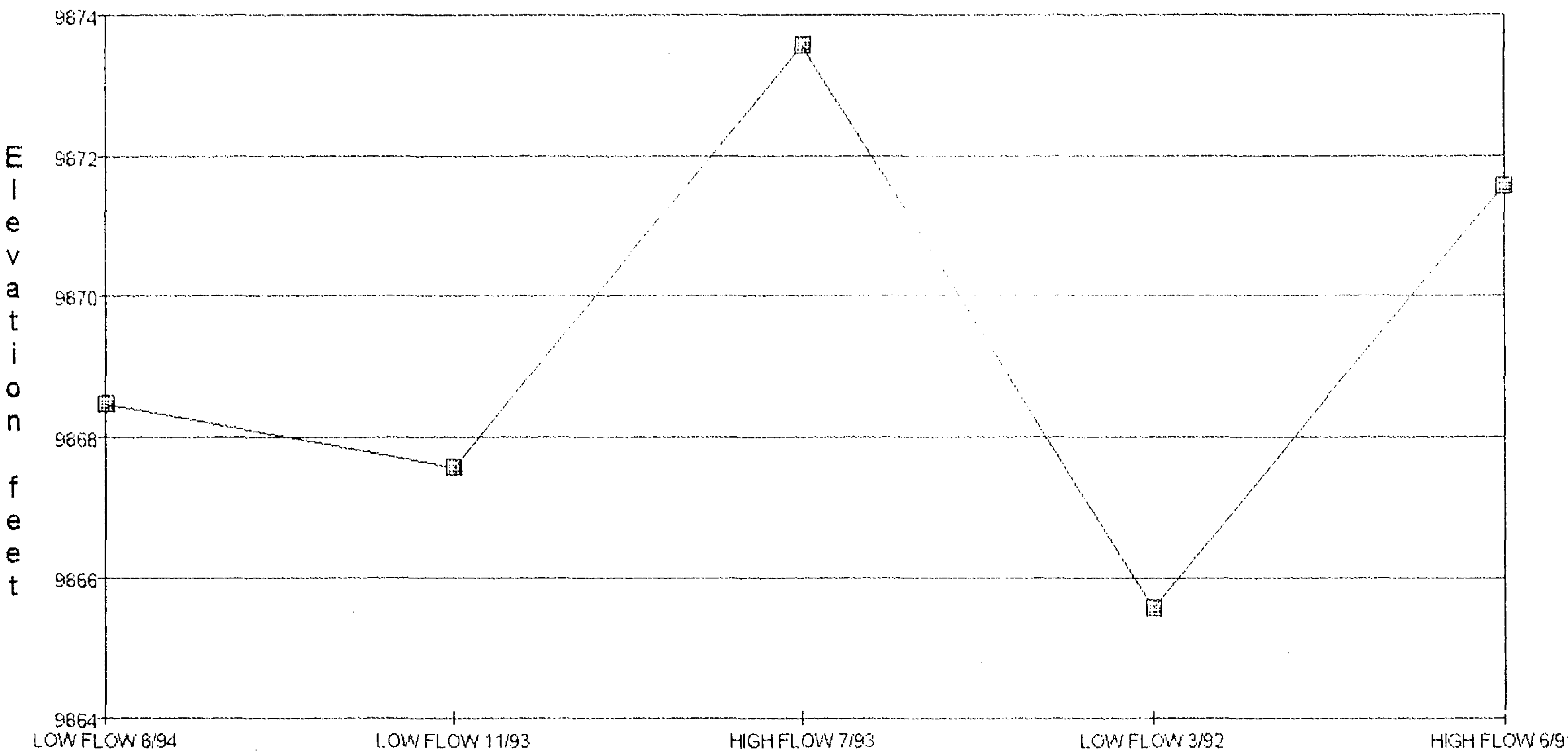
French Gulch Well #3
9850
9848
9846
9844
9842
9840
Elevation feet
LOW FLOW 8/94
LOW FLOW 11/93
HIGH FLOW 7/93
HIGH FLOW 6/93
LOW FLOW 3/92
STATIC WATER LEVELS


6

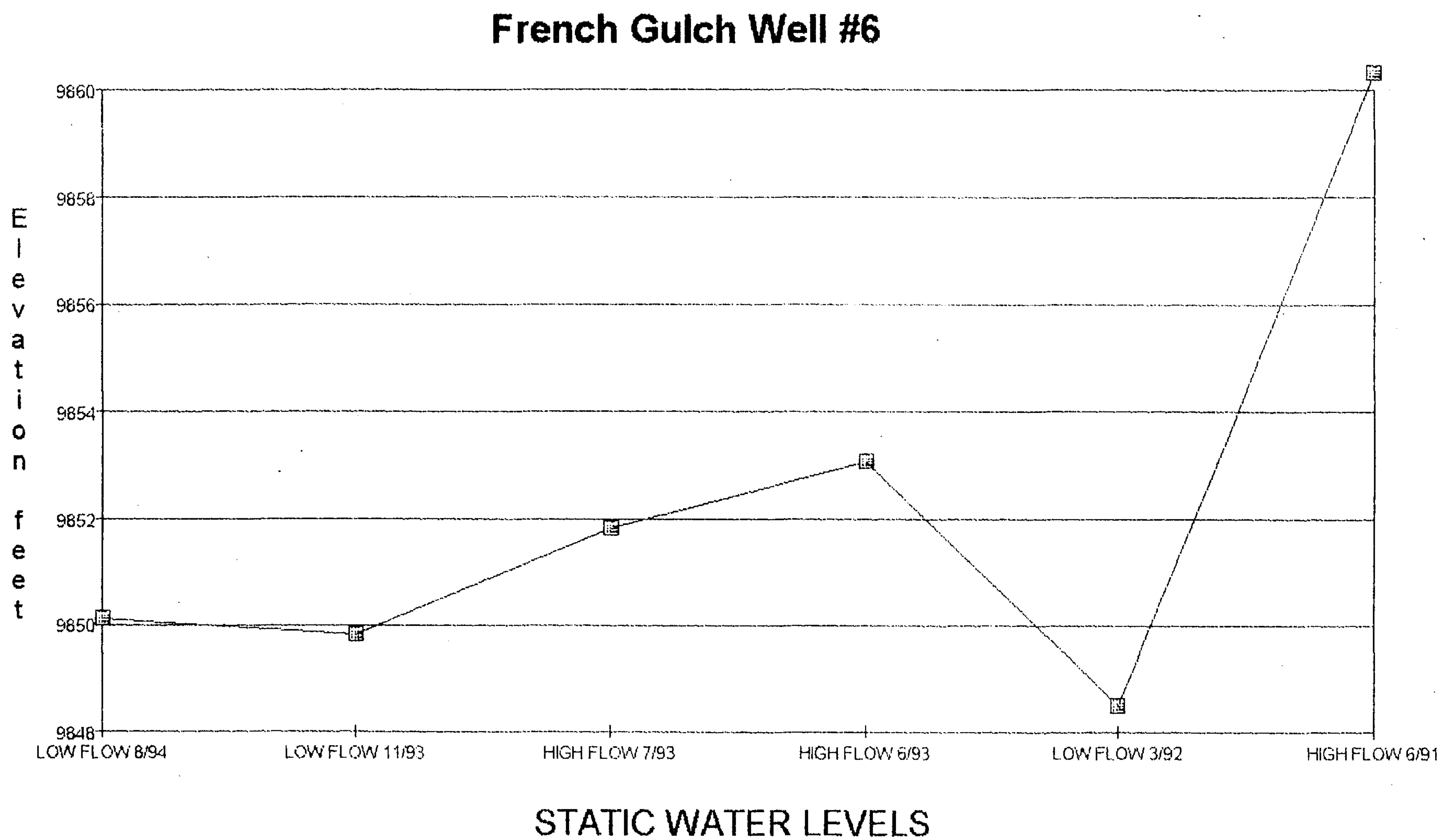

French Gulch Well #4
Elevation feet
9876
9874
9872
9870
9868
9866
LOW FLOW 11/94
HIGH FLOW 7/93
LOW FLOW 3/92
HIGH FLOW 11/91
STATIC WATER LEVELS

6

# French Gulch Well #5

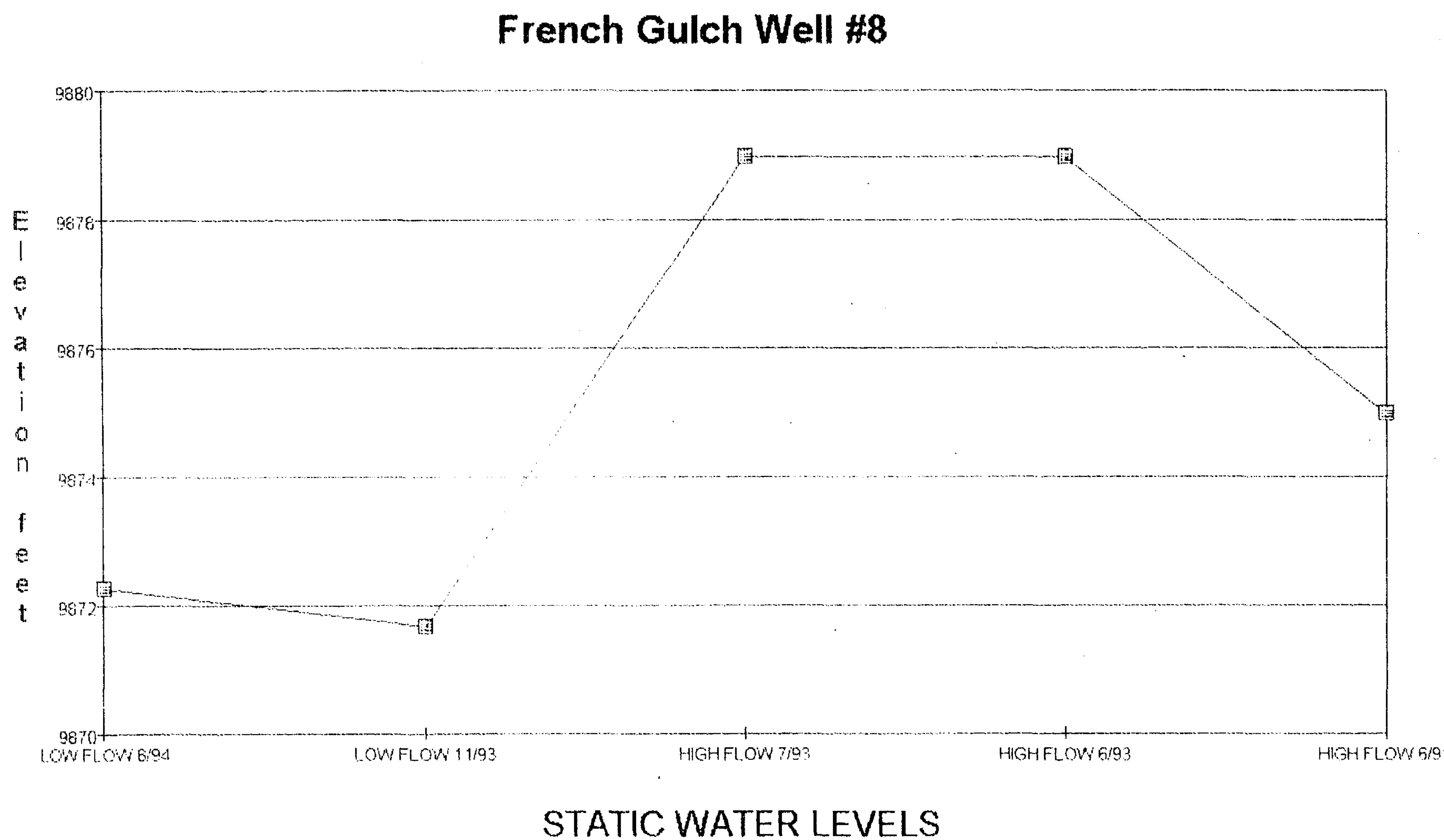



STATIC WATER LEVELS


French Gulch Well #6
Elevation feet
9860
9858
9856
9854
9852
9850
9848
LOW FLOW 8/94
LOW FLOW 11/93
HIGH FLOW 7/93
HIGH FLOW 6/93
LOW FLOW 3/92
HIGH FLOW 6/91
STATIC WATER LEVELS

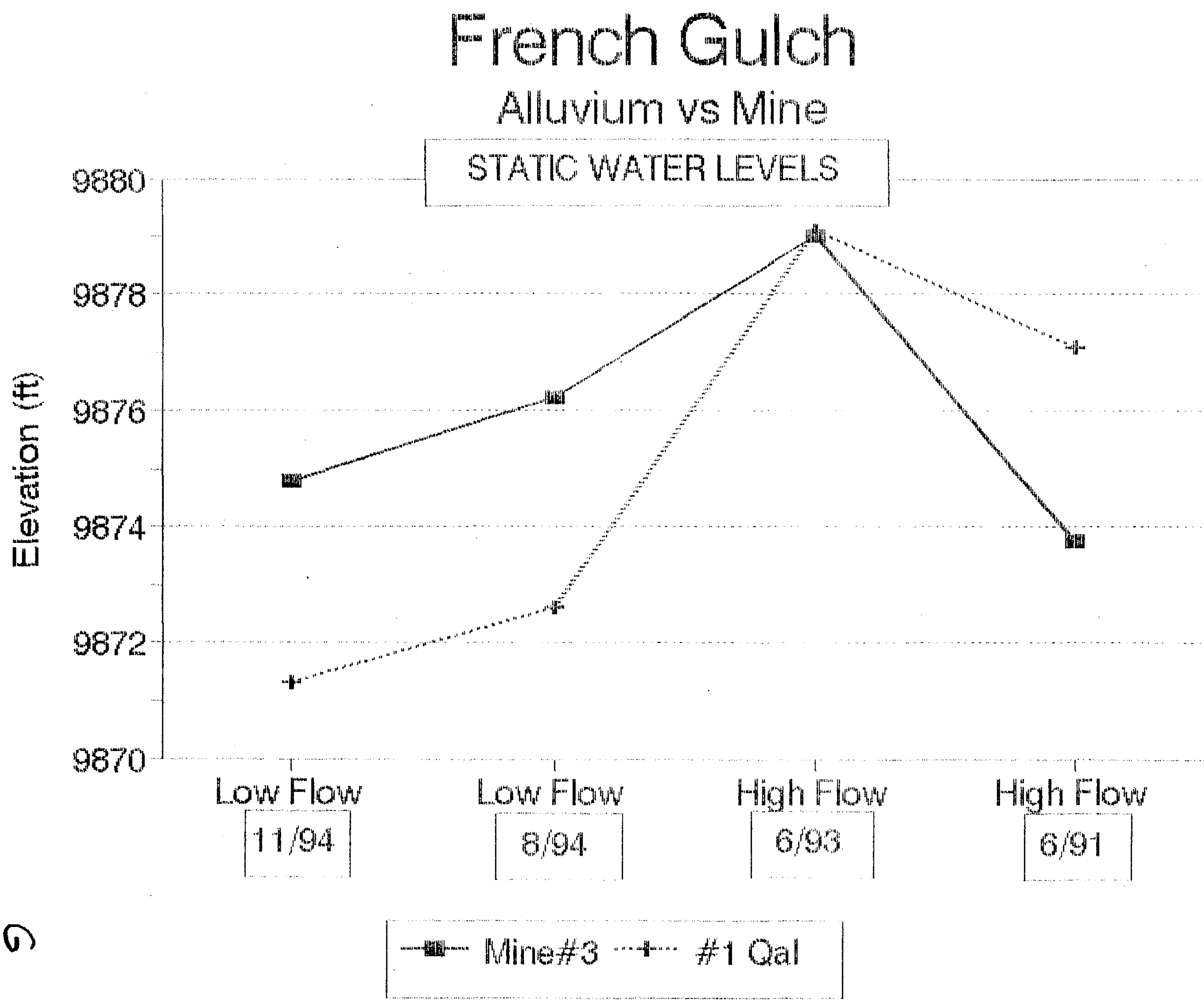
6

6



French Gulch Well #8
9880
9878
9876
9874
9872
9870
Elevation feet
LOW FLOW 6/94
LOW FLOW 11/93
HIGH FLOW 7/93
HIGH FLOW 6/93
HIGH FLOW 6/91
STATIC WATER LEVELS


6


French Gulch
Alluvium vs Mine
STATIC WATER LEVELS
Elevation (ft)
9880
9878
9876
9874
9872
9870
Low Flow
11/94
Low Flow
8/94
High Flow
6/93
High Flow
6/91
Mine#3
#1 Qal

9

# FRENCH GULCH D-20

| Chemical analysis | Well #1 ALL. only mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 14.04 | 0.61 | |
| K | 2.90 | 0.07 | |
| Mg | 119.40 | 9.55 | |
| Ca | 388.00 | 19.40 | |
| Fe | 108.84 | 3.90 | |
| Mn | 34.36 | 1.25 | |
| Zn | 131.90 | 4.03 | |
| Totals | | 38.82 | |
| anions | | | |
| HCO3 | 78.00 | 1.28 | |
| Cl | 2.45 | 0.07 | |
| SO4 | 1750.00 | 36.19 | |
| F | 3.10 | 0.12 | |
| Totals | | 37.66 | |
| cation/anion ratio= | 1.03 | | |

| Chemical analysis | Well #3 ALL. only mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 10.36 | 0.45 | |
| K | 2.20 | 0.06 | |
| Mg | 97.64 | 7.81 | |
| Ca | 311.00 | 15.55 | |
| Fe | 243.40 | 8.72 | |
| Mn | 42.60 | 1.55 | |
| Zn | 140.48 | 4.30 | |
| Totals | | 38.43 | |
| anions | | | |
| HCO3 | 21.00 | 0.34 | |
| Cl | 2.40 | 0.07 | |
| SO4 | 1750.00 | 36.19 | |
| F | 1.92 | 0.08 | |
| Totals | | 36.68 | |
| cation/anion ratio= | 1.05 | | |

| Chemical analysis | Well #2 ALL + ? mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 11.86 | 0.52 | |
| K | 3.00 | 0.08 | |
| Mg | 97.28 | 7.78 | |
| Ca | 448.00 | 22.40 | |
| Fe | 174.38 | 6.25 | |
| Mn | 30.24 | 1.10 | |
| Zn | 76.60 | 2.34 | |
| Totals | | 40.46 | |
| anions | | | |
| HCO3 | 82.00 | 1.35 | |
| Cl | 2.58 | 0.07 | |
| SO4 | 1710.00 | 35.36 | |
| F | 3.03 | 0.12 | |
| Totals | | 36.90 | |
| cation/anion ratio= | 1.10 | | |

| Chemical analysis | Well #4 ALL. + SH mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 14.16 | 0.62 | |
| K | 3.30 | 0.08 | |
| Mg | 113.40 | 9.07 | |
| Ca | 381.00 | 19.05 | |
| Fe | 82.54 | 2.96 | |
| Mn | 31.90 | 1.16 | |
| Zn | 123.72 | 3.78 | |
| Totals | | 36.72 | |
| anions | | | |
| HCO3 | 82.00 | 1.35 | |
| Cl | 2.54 | 0.07 | |
| SO4 | 1640.00 | 33.91 | |
| F | 2.96 | 0.12 | |
| Totals | | 35.45 | |
| cation/anion ratio= | 1.04 | | |

FRENCH GULCH CHEMICAL DATA D-20

| Chemical analysis | Well #5 ALL + SH mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 14.72 | 0.64 | |
| K | 3.40 | 0.09 | |
| Mg | 118.30 | 9.46 | |
| Ca | 401.00 | 20.05 | |
| Fe | 97.38 | 3.49 | |
| Mn | 34.00 | 1.24 | |
| Zn | 123.26 | 3.77 | |
| Totals | | 38.74 | |
| anions | | | |
| HCO3 | 102.00 | 1.68 | |
| Cl | 2.34 | 0.07 | |
| SO4 | 1870.00 | 38.67 | |
| F | 3.02 | 0.12 | |
| Totals | | 40.53 | |
| cation/anion ratio= | 0.96 | | |

| Chemical analysis | Well #7 ALL only mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 3.93 | 0.17 | |
| K | 1.50 | 0.04 | |
| Mg | 31.66 | 2.53 | |
| Ca | 134.00 | 6.70 | |
| Fe | 50.62 | 1.81 | |
| Mn | 15.36 | 0.56 | |
| Zn | 21.68 | 0.66 | |
| Totals | | 12.48 | |
| anions | | | |
| HCO3 | 43.00 | 0.71 | |
| Cl | 1.69 | 0.05 | |
| SO4 | 460.00 | 9.51 | |
| F | 0.96 | 0.04 | |
| Totals | | 10.30 | |
| cation/anion ratio= | 1.21 | | |

| Chemical analysis | Well #6 ALL + SH/LS ? mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 13.93 | 0.61 | |
| K | 3.70 | 0.10 | |
| Mg | 110.00 | 8.80 | |
| Ca | 434.00 | 21.70 | |
| Fe | 62.46 | 2.24 | |
| Mn | 21.48 | 0.78 | |
| Zn | 48.24 | 1.48 | |
| Totals | | 35.70 | |
| anions | | | |
| HCO3 | 114.00 | 1.87 | |
| Cl | 2.41 | 0.07 | |
| SO4 | 1580.00 | 32.67 | |
| F | 2.86 | 0.11 | |
| Totals | | 34.73 | |
| cation/anion ratio= | 1.03 | | |

| Chemical analysis | Well #8L SH + WLL mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 13.20 | 0.57 | |
| K | 2.80 | 0.07 | |
| Mg | 123.60 | 9.89 | |
| Ca | 378.00 | 18.90 | |
| Fe | 104.00 | 3.72 | |
| Mn | 43.62 | 1.59 | |
| Zn | 186.48 | 5.70 | |
| Totals | | 40.45 | |
| anions | | | |
| HCO3 | 76.00 | 1.25 | |
| Cl | 2.49 | 0.07 | |
| SO4 | 1850.00 | 38.25 | |
| F | 3.06 | 0.12 | |
| Totals | | 39.70 | |
| cation/anion ratio= | 1.02 | | |

FRENCH GULCH CHEMICAL DATA D-20

| Chemical analysis | Well #9 ALL. only mg/l | meq/l | Date 11/16/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 1.31 | 0.06 | |
| K | 1.00 | 0.03 | |
| Mg | 1.96 | 0.16 | |
| Ca | 24.63 | 1.23 | |
| Fe | 5.00 | 0.18 | |
| Mn | 8.00 | 0.29 | |
| Zn | 0.12 | 0.00 | |
| Totals | | 1.94 | |
| anions | | | |
| HCO3 | 51.00 | 0.84 | |
| Cl | 0.50 | 0.01 | |
| SO4 | 20.60 | 0.43 | |
| F | 0.20 | 0.01 | |
| Totals | | 1.29 | |
| cation/anion ratio= | 1.51 | | |

| Chemical analysis | Well #11 ALL. rsh mg/l | meq/l | Date 11/16/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 2.06 | 0.09 | |
| K | 1.10 | 0.03 | |
| Mg | 3.65 | 0.29 | |
| Ca | 29.43 | 1.47 | |
| Fe | 5.00 | 0.18 | |
| Mn | 0.06 | 0.00 | |
| Zn | 2.93 | 0.09 | |
| Totals | | 2.15 | |
| anions | | | |
| HCO3 | 45.00 | 0.74 | |
| Cl | 1.55 | 0.04 | |
| SO4 | 45.70 | 0.94 | |
| F | 0.20 | 0.01 | |
| Totals | | 1.74 | |
| cation/anion ratio= | 1.24 | | |

| Chemical analysis | Well #8U ALL. mg/l | meq/l | Date 11/17/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 13.02 | 0.57 | |
| K | 2.30 | 0.06 | |
| Mg | 135.10 | 10.81 | |
| Ca | 378.00 | 18.90 | |
| Fe | 429.00 | 15.37 | |
| Mn | 50.42 | 1.84 | |
| Zn | 25.20 | 0.77 | |
| Totals | | 48.30 | |
| anions | | | |
| HCO3 | 0.00 | 0.00 | |
| Cl | 3.67 | 0.10 | |
| SO4 | 2610.00 | 53.97 | |
| F | 4.30 | 0.17 | |
| Totals | | 54.25 | |
| cation/anion ratio= | 0.89 | | |

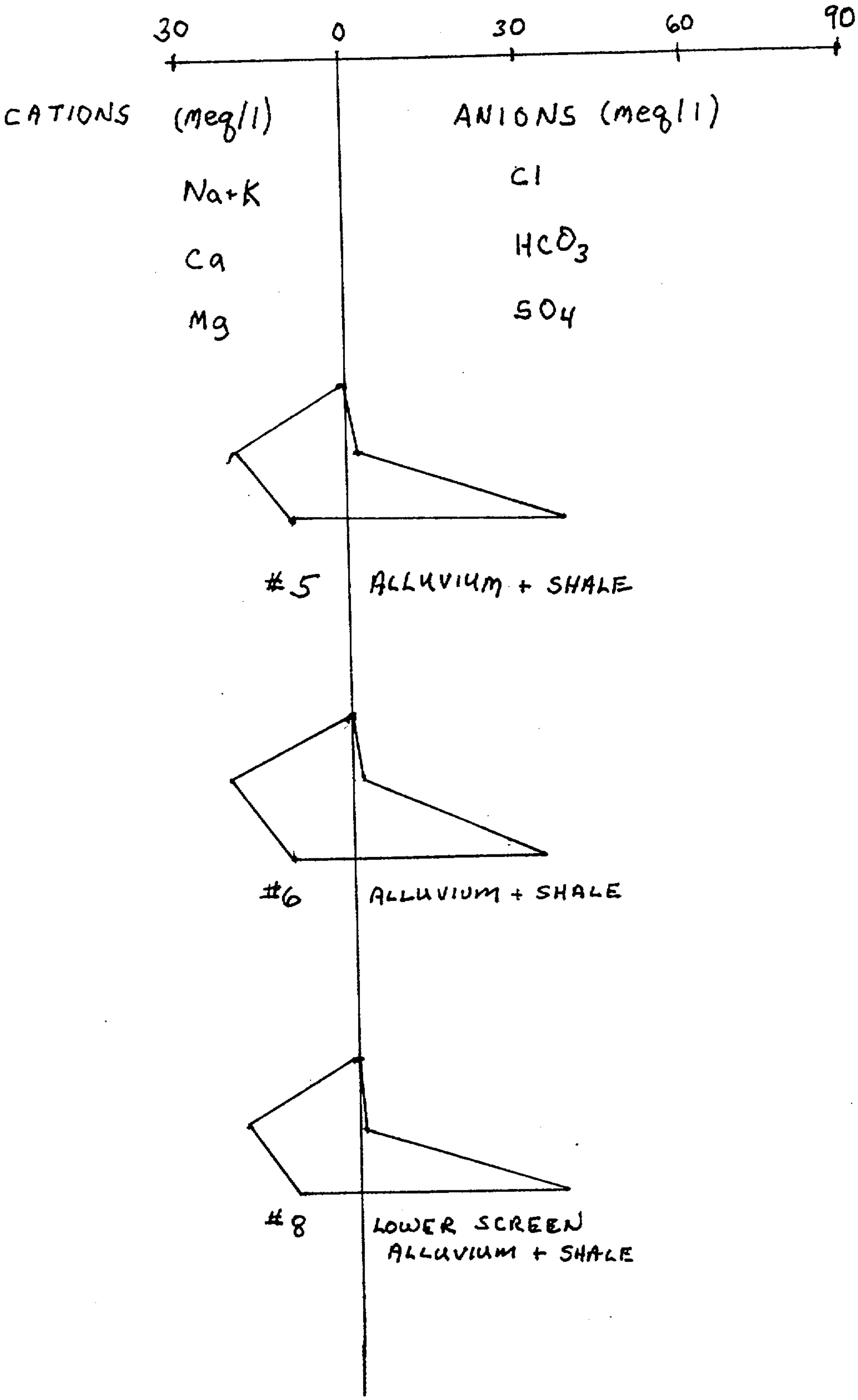
| Chemical analysis | Well #12 Porphyry mg/l | meq/l | Date 11/16/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 5.19 | 0.23 | |
| K | 5.10 | 0.13 | |
| Mg | 5.65 | 0.45 | |
| Ca | 38.38 | 1.92 | |
| Fe | 5.00 | 0.18 | |
| Mn | 0.11 | 0.00 | |
| Zn | 0.11 | 0.00 | |
| Totals | | 2.91 | |
| anions | | | |
| HCO3 | 82.00 | 1.35 | |
| Cl | 3.29 | 0.09 | |
| SO4 | 54.80 | 1.13 | |
| F | 0.20 | 0.01 | |
| Totals | | 2.58 | |
| cation/anion ratio= | 1.13 | | |

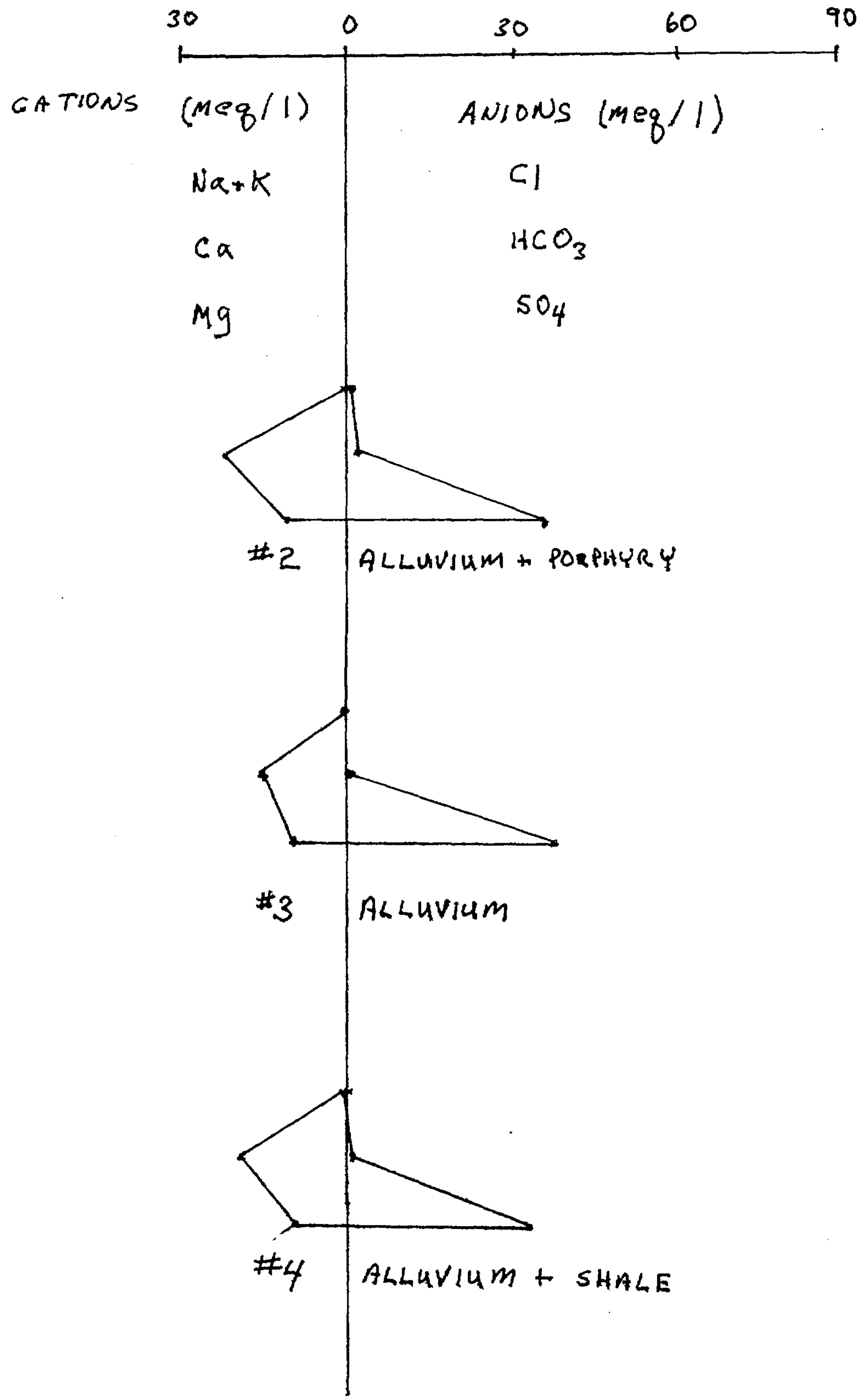
D-20

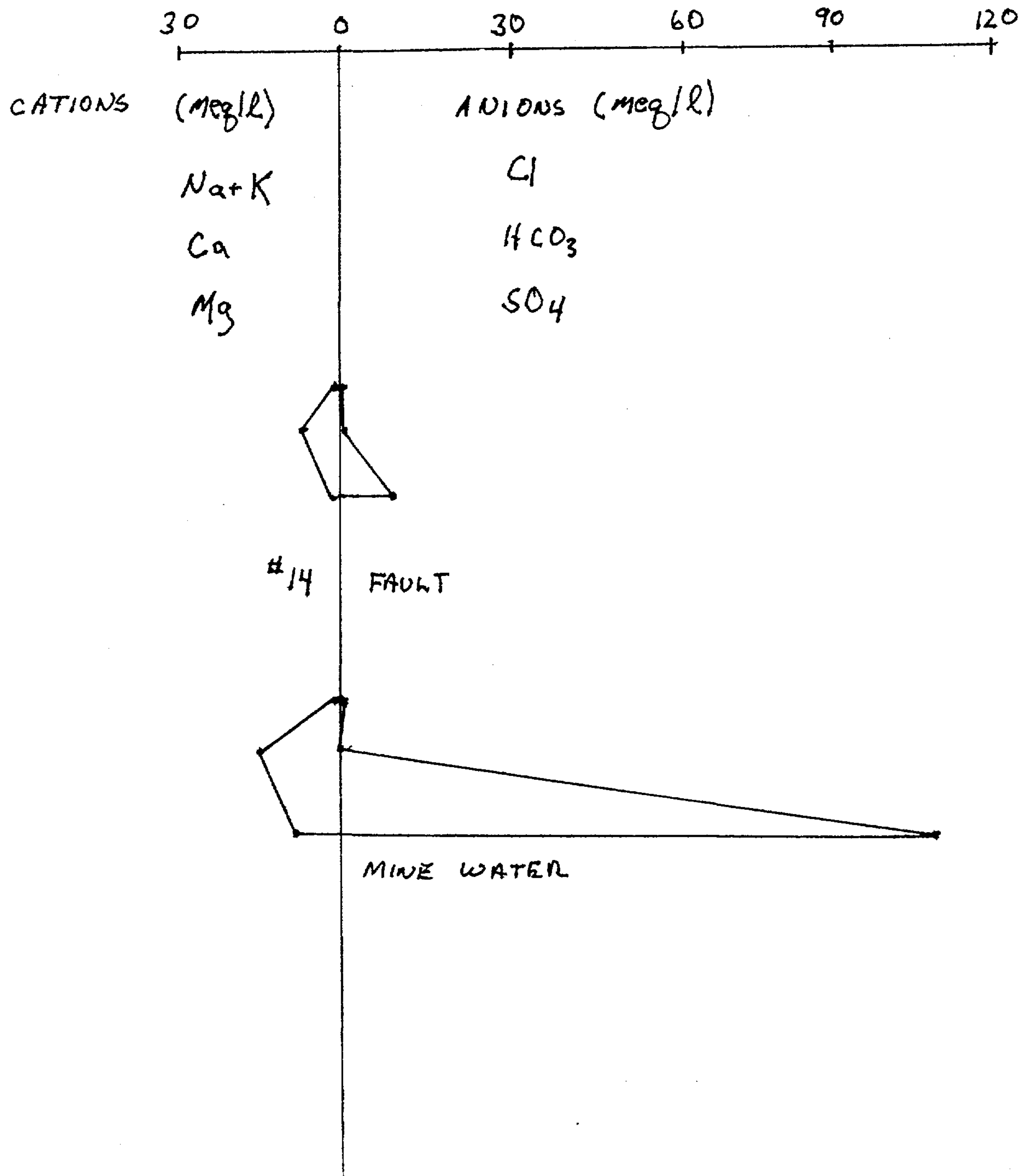
| Chemical analysis | Well #13 -SHALE mg/l | meq/l | Date 11/16/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 23.97 | 1.04 | |
| K | 10.80 | 0.28 | |
| Mg | 228.10 | 18.25 | |
| Ca | 393.80 | 19.69 | |
| Fe | 20.47 | 0.73 | |
| Mn | 130.06 | 4.73 | |
| Zn | 1495.00 | 45.73 | |
| Totals | | 90.46 | |
| anions | | | |
| HCO3 | 23.00 | 0.38 | |
| Cl | 7.49 | 0.21 | |
| SO4 | 4190.00 | 86.64 | |
| F | 5.95 | 0.24 | |
| Totals | | 87.47 | |
| cation/anion ratio= | 1.03 | | |

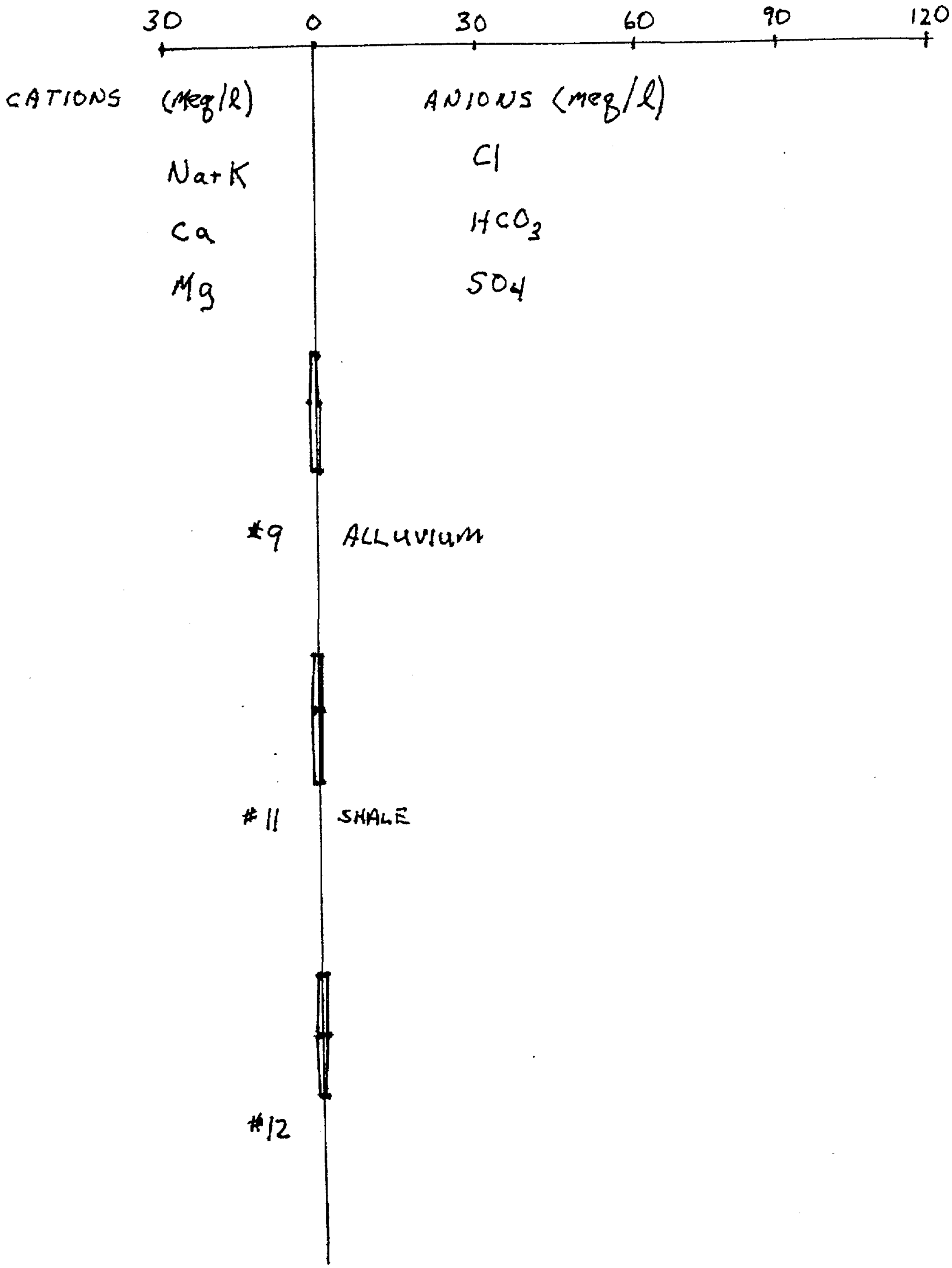
| Chemical analysis | Well #14 mg/l | meq/l | Date 11/16/93 meq(%) |
|---|---|---|---|
| cations | | | |
| Na | 22.25 | 0.97 | |
| K | 3.10 | 0.08 | |
| Mg | 34.02 | 2.72 | |
| Ca | 215.20 | 10.76 | |
| Fe | 0.12 | 0.00 | |
| Mn | 0.49 | 0.02 | |
| Zn | 0.07 | 0.00 | |
| Totals | | 14.55 | |
| anions | | | |
| HCO3 | 108.00 | 1.77 | |
| Cl | 15.30 | 0.43 | |
| SO4 | 560.00 | 11.58 | |
| F | 0.99 | 0.04 | |
| Totals | | 13.83 | |
| cation/anion ratio= | 1.05 | | |

| Chemical analysis | Mine Water mg/l | meq/l Date 3/9/93 |
|---|---|---|
| cations | | |
| Na | 20.5 | 0.89 |
| K | 5.2 | 0.14 |
| Mg | 185 | 14.80 |
| Ca | 365 | 18.25 |
| Fe | 2040 | 73.10 |
| Mn | 310 | 11.28 |
| Zn | 158 | 4.83 |
| Totals | | 123.29 |
| anions | | |
| HCO3 | 0 | 0 |
| Cl | 45 | 1.26 |
| SO4 | 5348 | 110.58 |
| F | 0 | 0 |
| Totals | | 111.84 |
| cation/anion ratio= | 1.10 | |


30
0
30
60
90
CATIONS (meq/l)
ANIONS (meq/l)
Na+K
Cl
Ca
HCO3
Mg
SO4
#5
ALLUVIUM + SHALE
#6
ALLUVIUM + SHALE
#8
LOWER SCREEN
ALLUVIUM + SHALE


30
0
30
60
90
CATIONS (meq/l)
ANIONS (meq/l)
Na+K
Cl
Ca
HCO3
Mg
SO4
#2
ALLUVIUM + PORPHYRY
#3
ALLUVIUM
#4
ALLUVIUM + SHALE

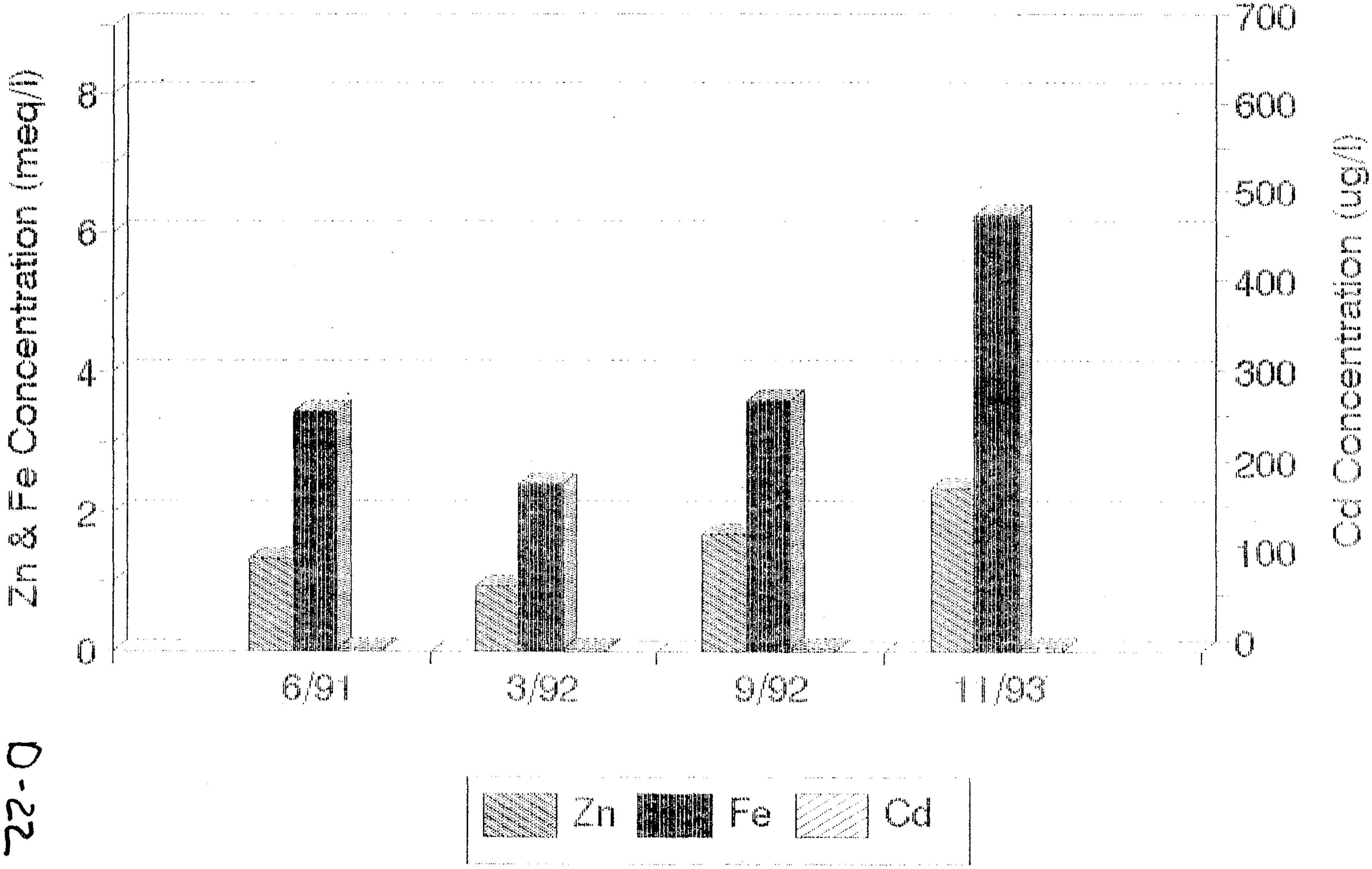

30 0 30 60 90 120
CATIONS (meq/l)
ANIONS (meq/l)
Na+K
Ca
Mg
Cl
HCO3
SO4
#14 FAULT
MINE WATER



30
0
30
60
90
120
CATIONS (meq/l)
ANIONS (meq/l)
Na+K
Cl
Ca
$HCO_3$
Mg
SO4
#9 ALLUVIUM
#11 SHALE
#12

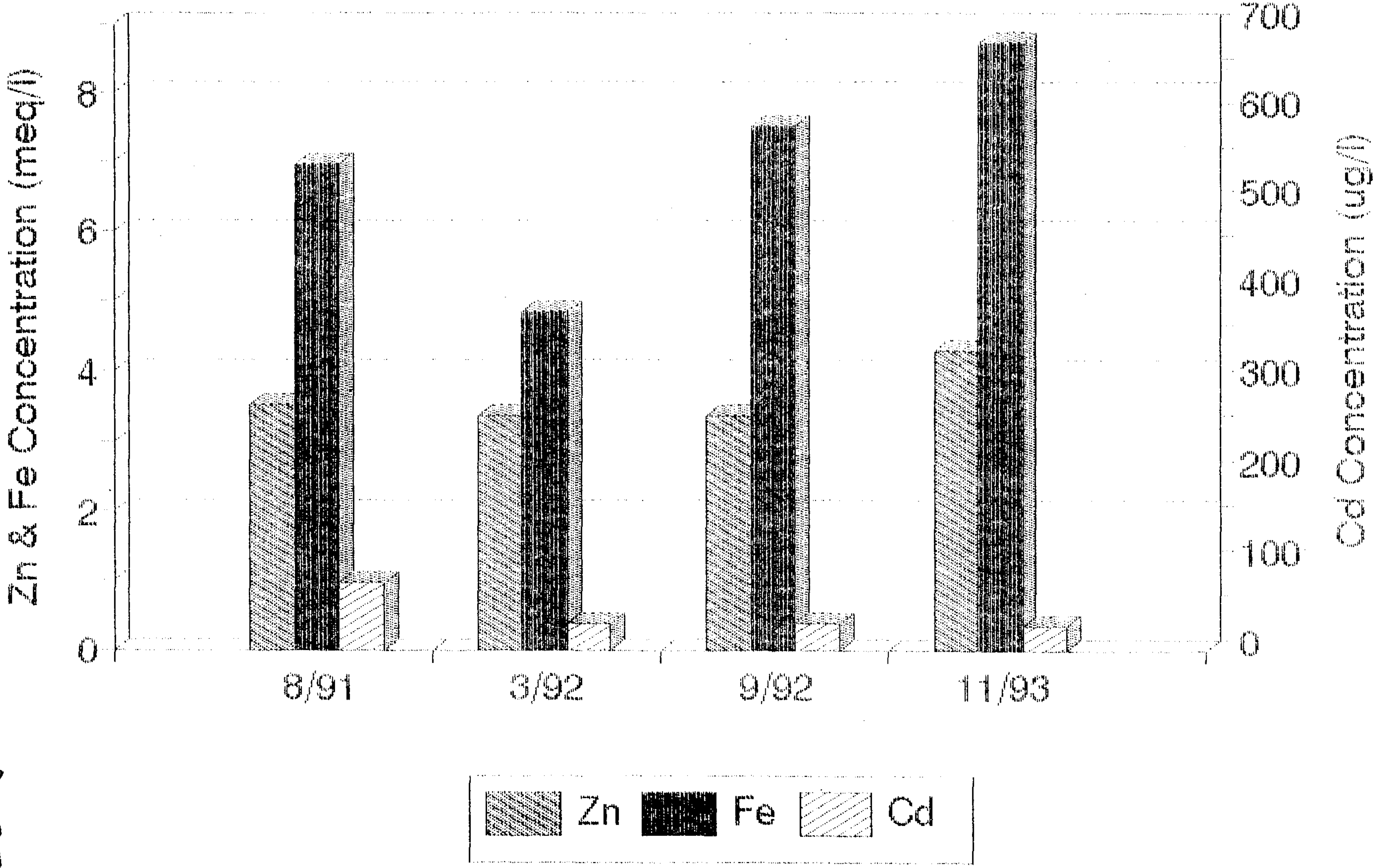
# French Gulch Well 2

## Well Water Chemistry



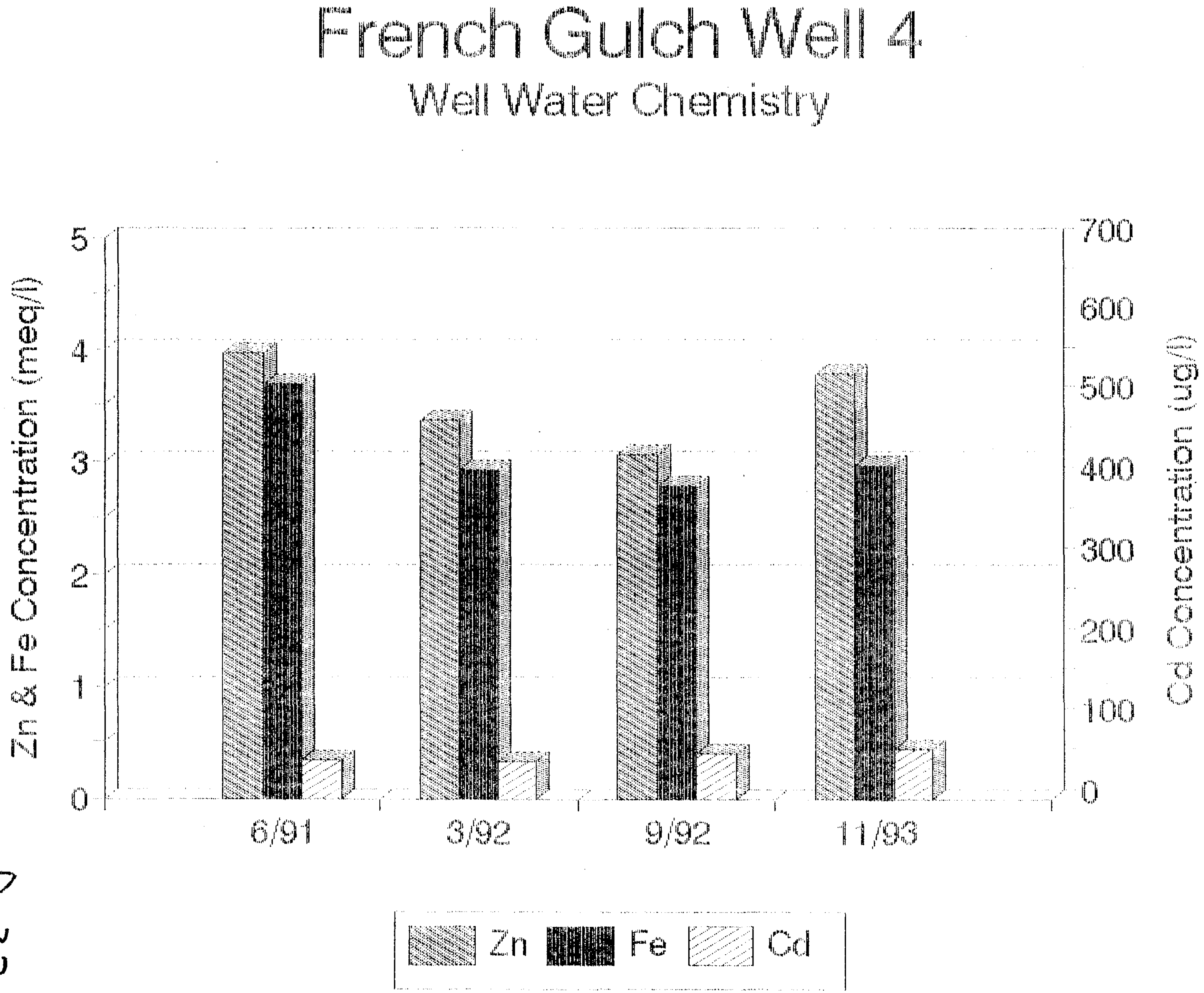
# French Gulch Well 3

## Well Water Chemistry




D-22

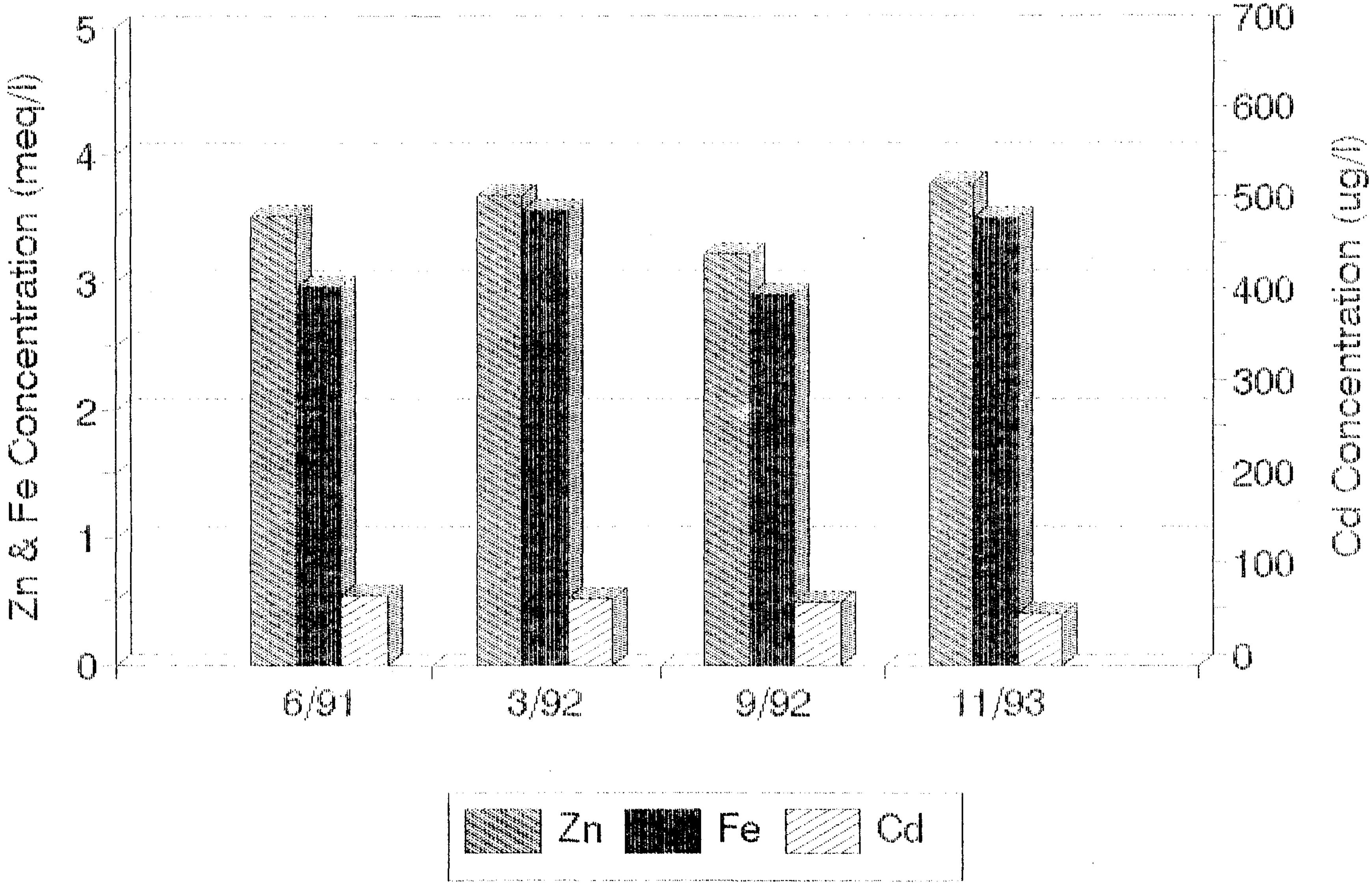
D-22


French Gulch Well 4
Well Water Chemistry
Zn & Fe Concentration (meq/l)
Cd Concentration (ug/l)
0
1
2
3
4
5
0
100
200
300
400
500
600
700
6/91
3/92
9/92
11/93
Zn
Fe
Cd

D-22

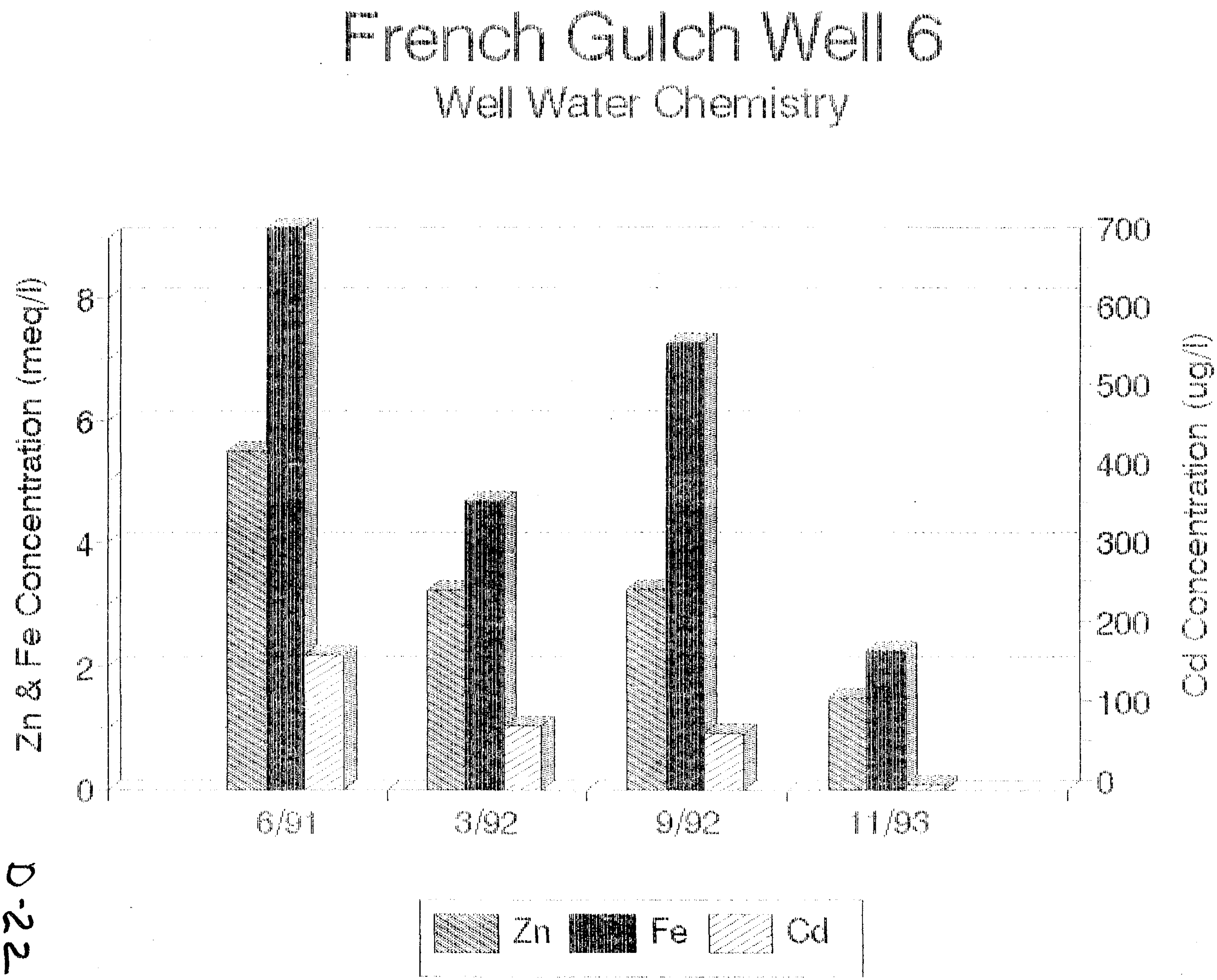
# French Gulch Well 5

## Well Water Chemistry



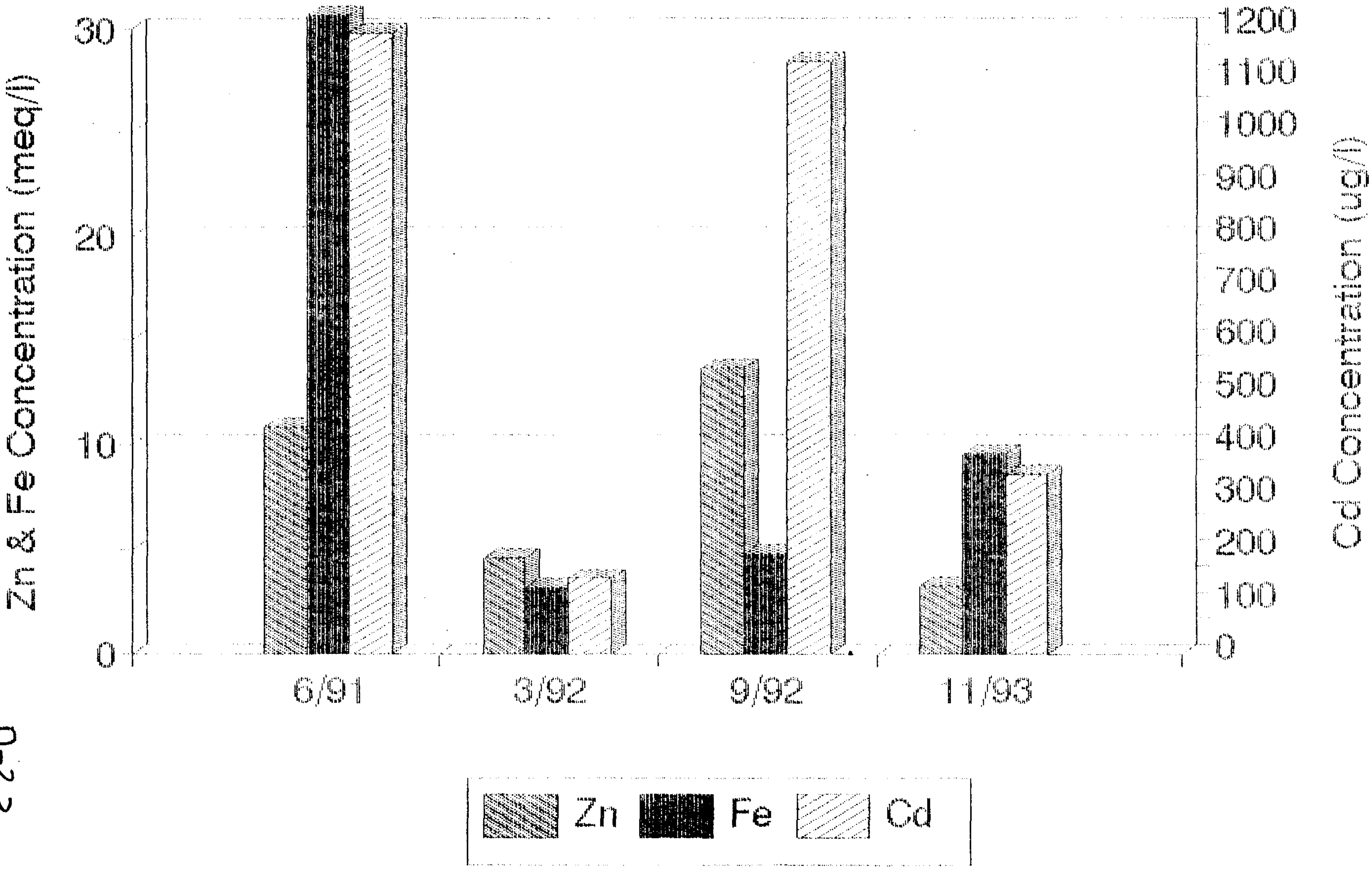

D-22

D-22


French Gulch Well 6
Well Water Chemistry
Zn & Fe Concentration (meq/l)
Cd Concentration (ug/l)
0
2
4
6
8
0
100
200
300
400
500
600
700
6/91
3/92
9/92
11/93
Zn
Fe
Cd

# French Gulch Well 8

## Well Water Chemistry




D-22

D-22

# APPENDIX
# E

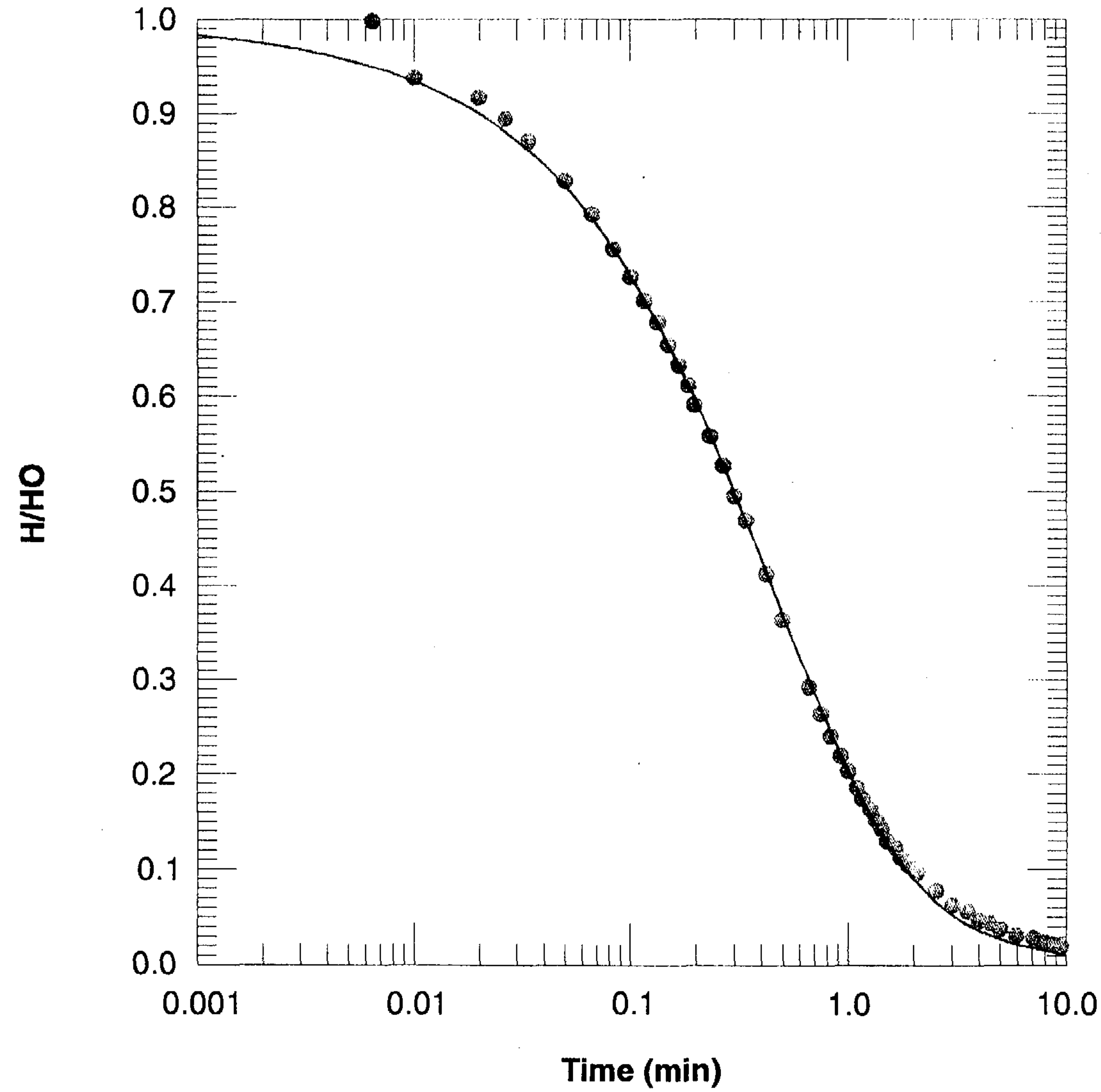
## AQTESOLV CURVE-MATCHING FOR RISING HEAD (RH) AND FALLING HEAD (FH) SLUG TESTS

### FRENCH GULCH MONITORING WELLS

#11
#1
#2
#3
#7
#8

| Research Project | Client: EPA/CDH/CMG |
|---|---|
| Project No: Wellington Mine | Location: Breckenridge, CO |

# French Gulch Mine Hydrology - Well 11FH




**DATA SET**
wm11fhst.dat
10/14/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
11

**OBS. WELL**
11

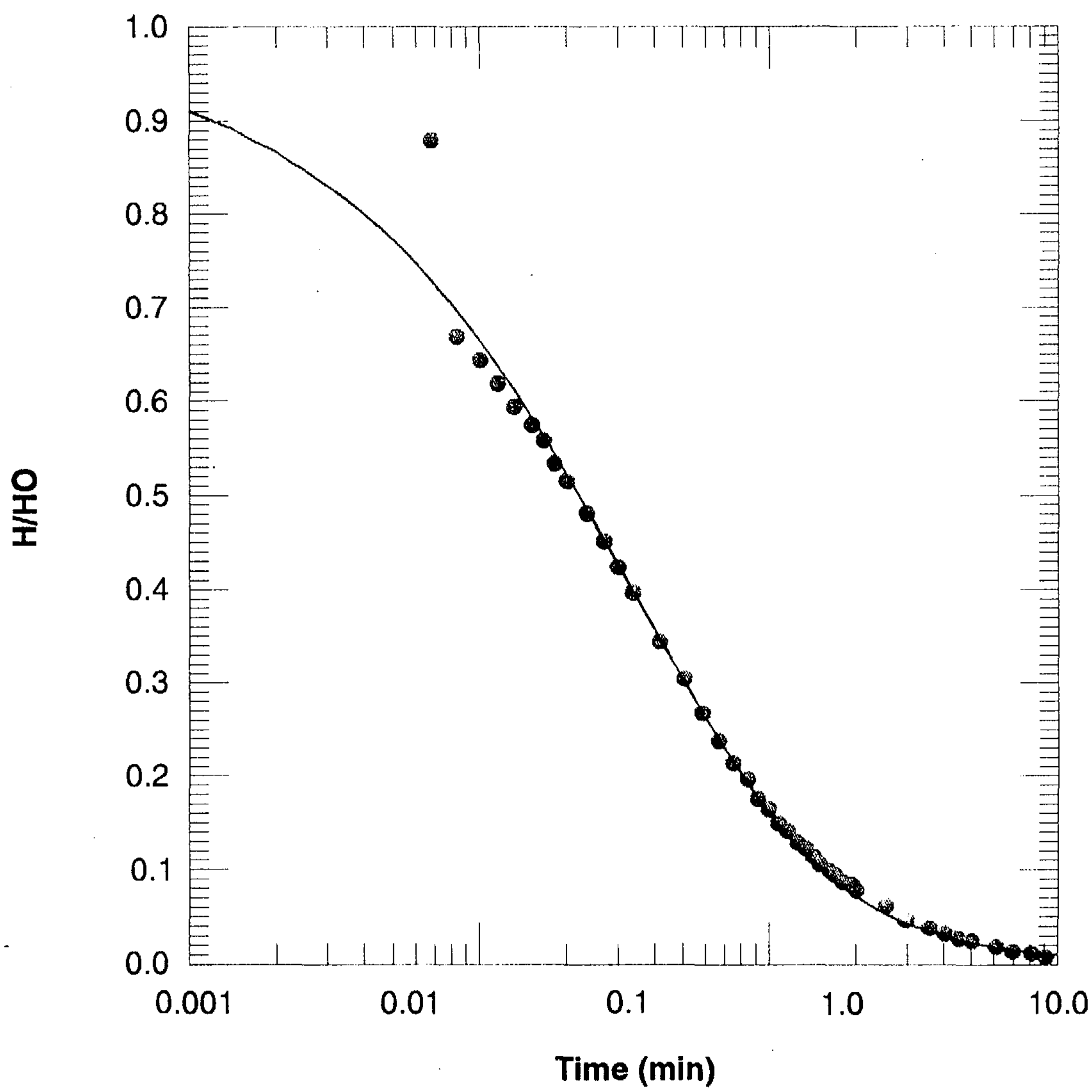
**ESTIMATED PARAMETERS**
$T = 0.0173\ ft^2/min$
$S = 0.004355$

**TEST DATA**
$HO = 4.3$ ft
$rc = 0.08333$ ft
$rw = 0.1667$ ft

11FH.CDR

| Research Project | Client: EPA/CDH/CMG |
|---|---|
| Project No: Wellington Mine | Location: Breckenridge, CO |

# French Gulch Mine Hydrology - Well 11RH




**DATA SET**
wm11rhst.dat
10/14/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
11

**OBS. WELL**
11

**ESTIMATED PARAMETERS**
T = 0.01902 $ft^2$/min
S = 0.009129

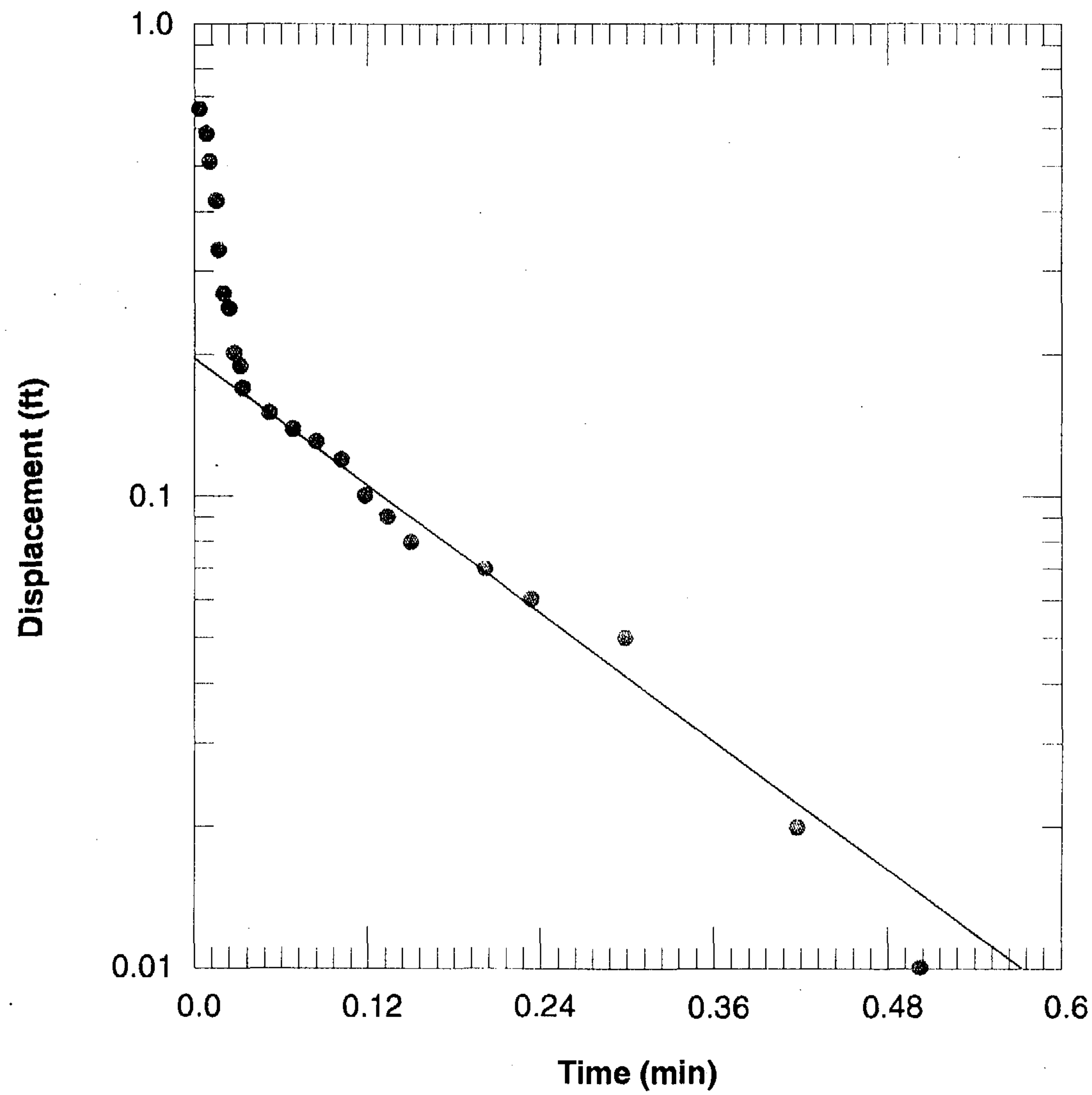
**TEST DATA**
HO = 4.92 ft
rc = 0.08333 ft
rw = 0.1667 ft

11RH.CDR

E

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 01RH




**DATA SET**
wm01rhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
01

**OBS. WELL**
01

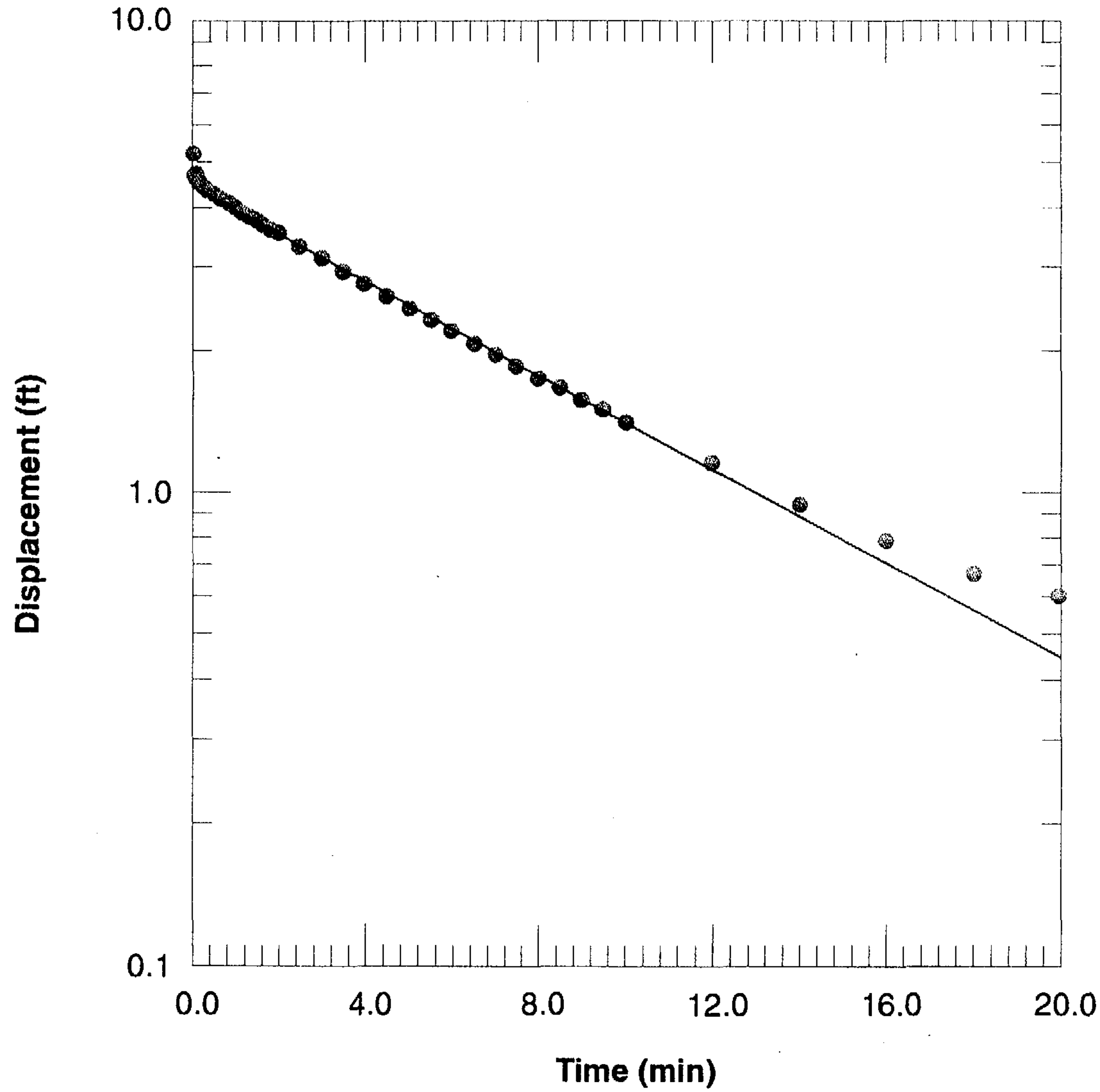
**ESTIMATED PARAMETERS**
K = 0.005343 ft/min
y0 = 0.1966 ft.

**TEST DATA**
HO = 4 ft
rc = 0.833 ft
rw = 0.1667 ft
L = 13 ft
b = 29 ft
H = 29 ft

01RH2.CDR

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 02RH




**DATA SET**
wm02rhst.dat
10/17/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
02

**OBS. WELL**
02

**ESTIMATED PARAMETERS**
K = 0.0001537 ft/min
y0 = 4.433 ft.

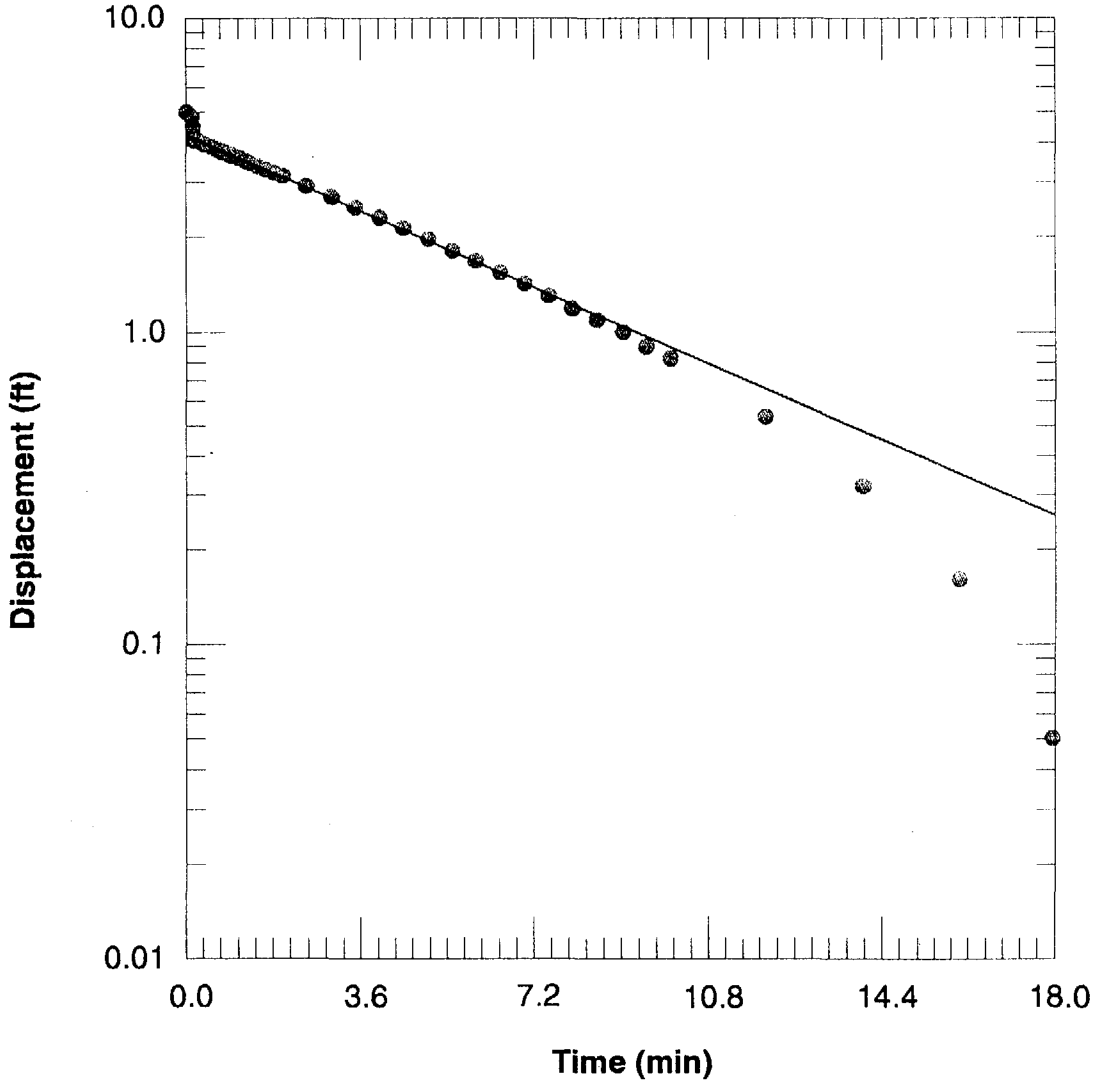
**TEST DATA**
HO = 5.2 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 10 ft
b = 25 ft
H = 32 ft

E

02RH1.CDR

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 02FH




**DATA SET**
wm02fhst.dat
10/17/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
02

**OBS. WELL**
02

**ESTIMATED PARAMETERS**
K = 0.0002082 ft/min
y0 = 4.238 ft.

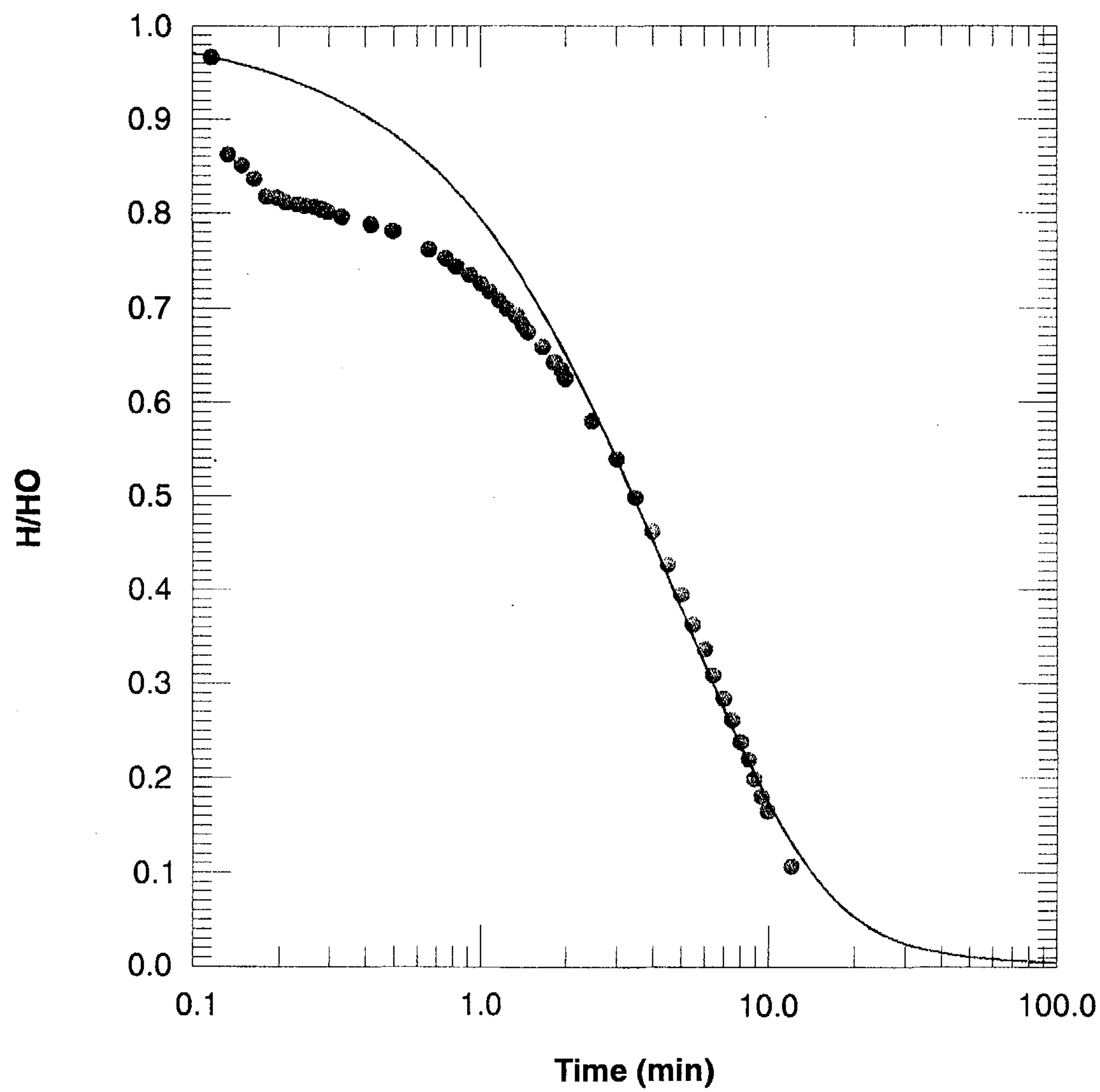
**TEST DATA**
HO = 5 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 10 ft
b = 25 ft
H = 32 ft

02FH1.CDR

E

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 02FH




**DATA SET**
wm02fhst.dat
10/17/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
02

**OBS. WELL**
02

**ESTIMATED PARAMETERS**
T = 0.0044 $ft^2$/min
S = 2.5168E-06

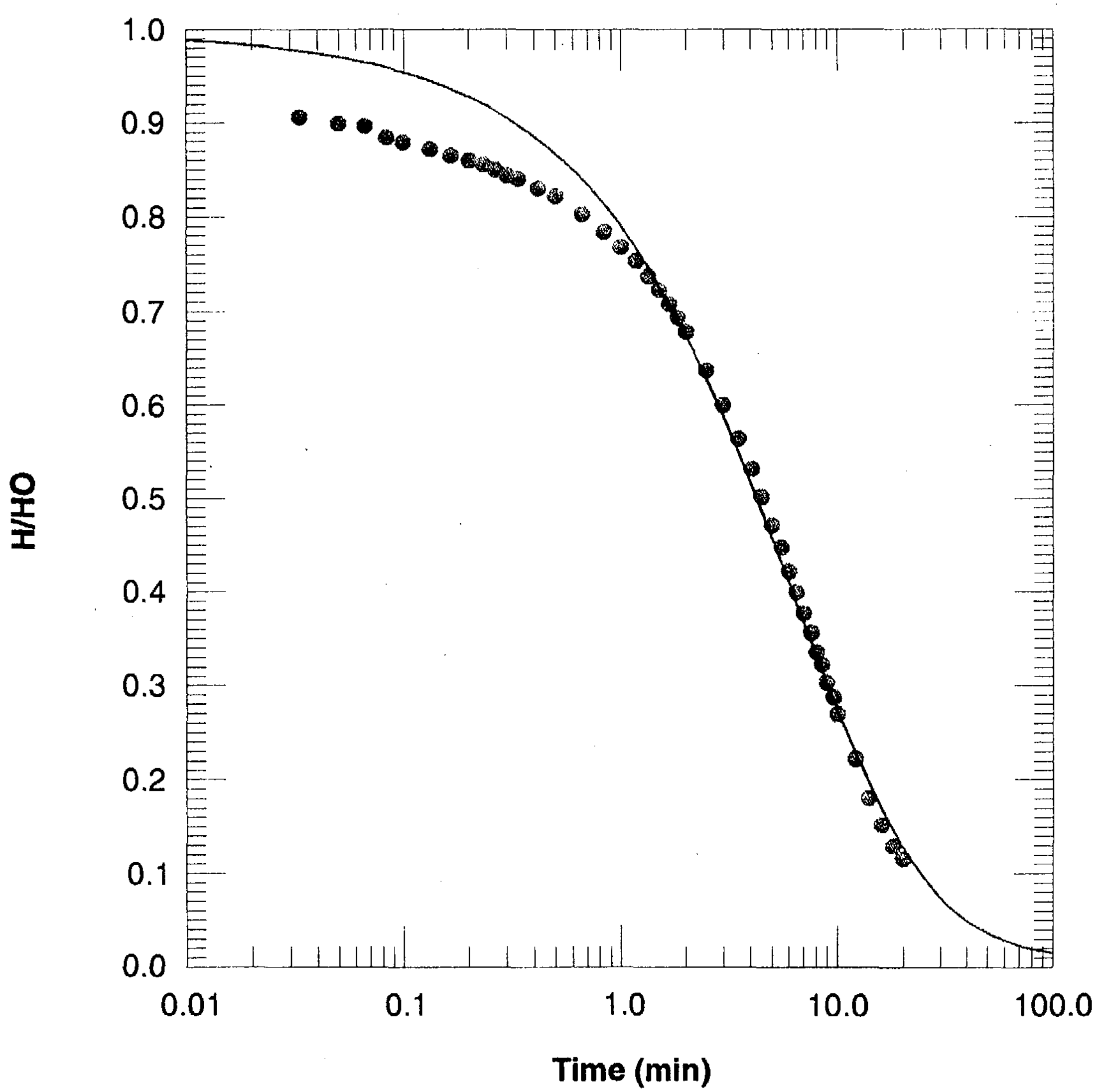
**TEST DATA**
HO = 5 ft
rc = 0.08333 ft
rw = 0.1667 ft

E

W02FH.CDR

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 02RH




**DATA SET**
wm02rhst.dat
10/17/94

**AQUIFER TYPE**
Confined

**SOLUTION METHOD**
Cooper et. al.

**TEST DATA**
10/12/94

**TEST WELL**
02

**OBS. WELL**
02

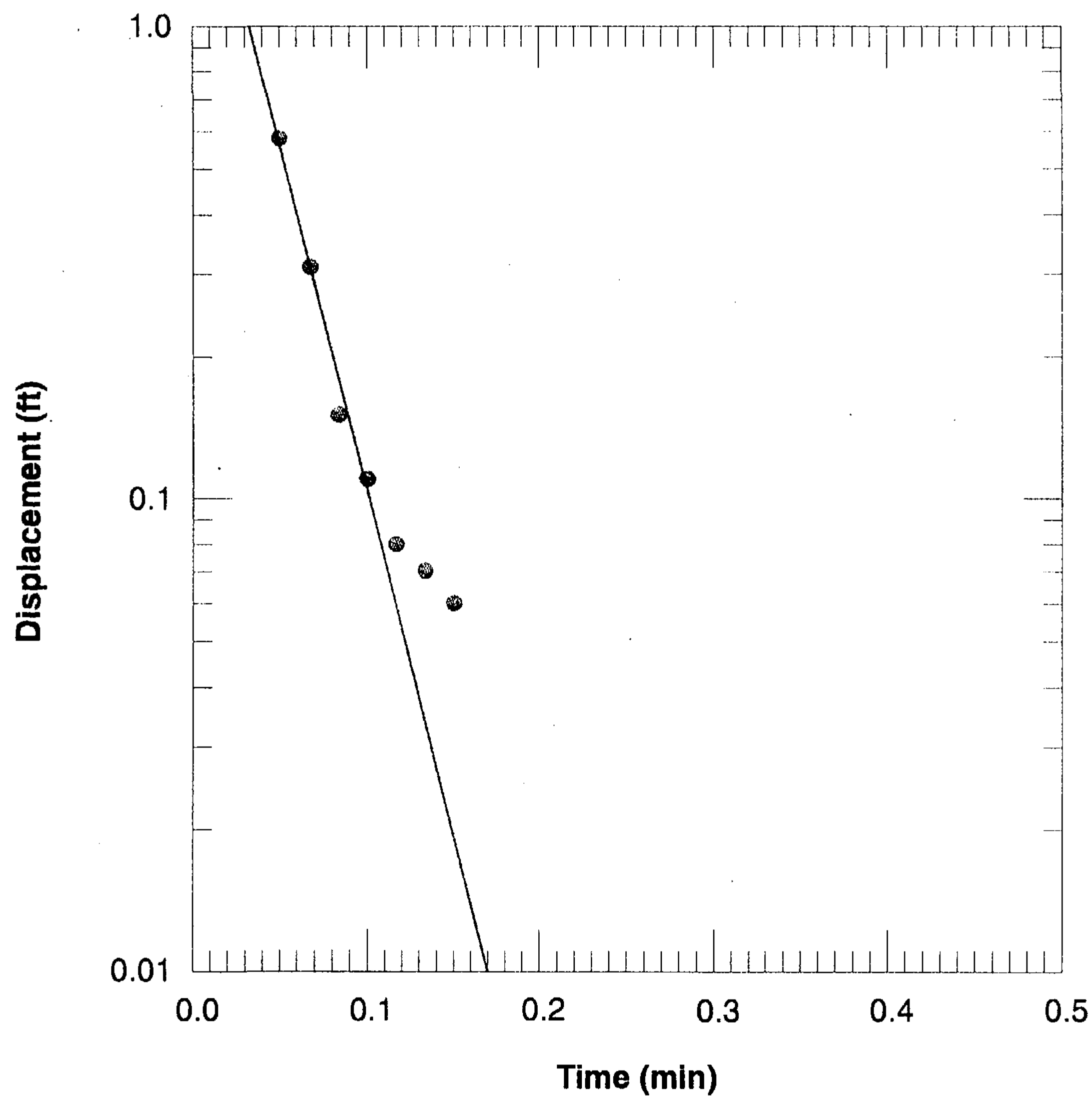
**ESTIMATED PARAMETERS**
T = 0.001442 $ft^2$/min
S = 0.002102

**TEST DATA**
HO = 5.2 ft
rc = 0.08333 ft
rw = 0.1667 ft

W02RH.CDR

| Research Project | Client: EPA/CDH/CMG |
|---|---|
| Project No: Wellington Mine | Location: Breckenridge, CO |

# French Gulch Mine Hydrology - Well 03FH




**DATA SET**
wm03fhst.dat
10/17/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
03

**OBS. WELL**
03

**ESTIMATED PARAMETERS**
K = 0.03159 ft/min
y0 = 3.067 ft.

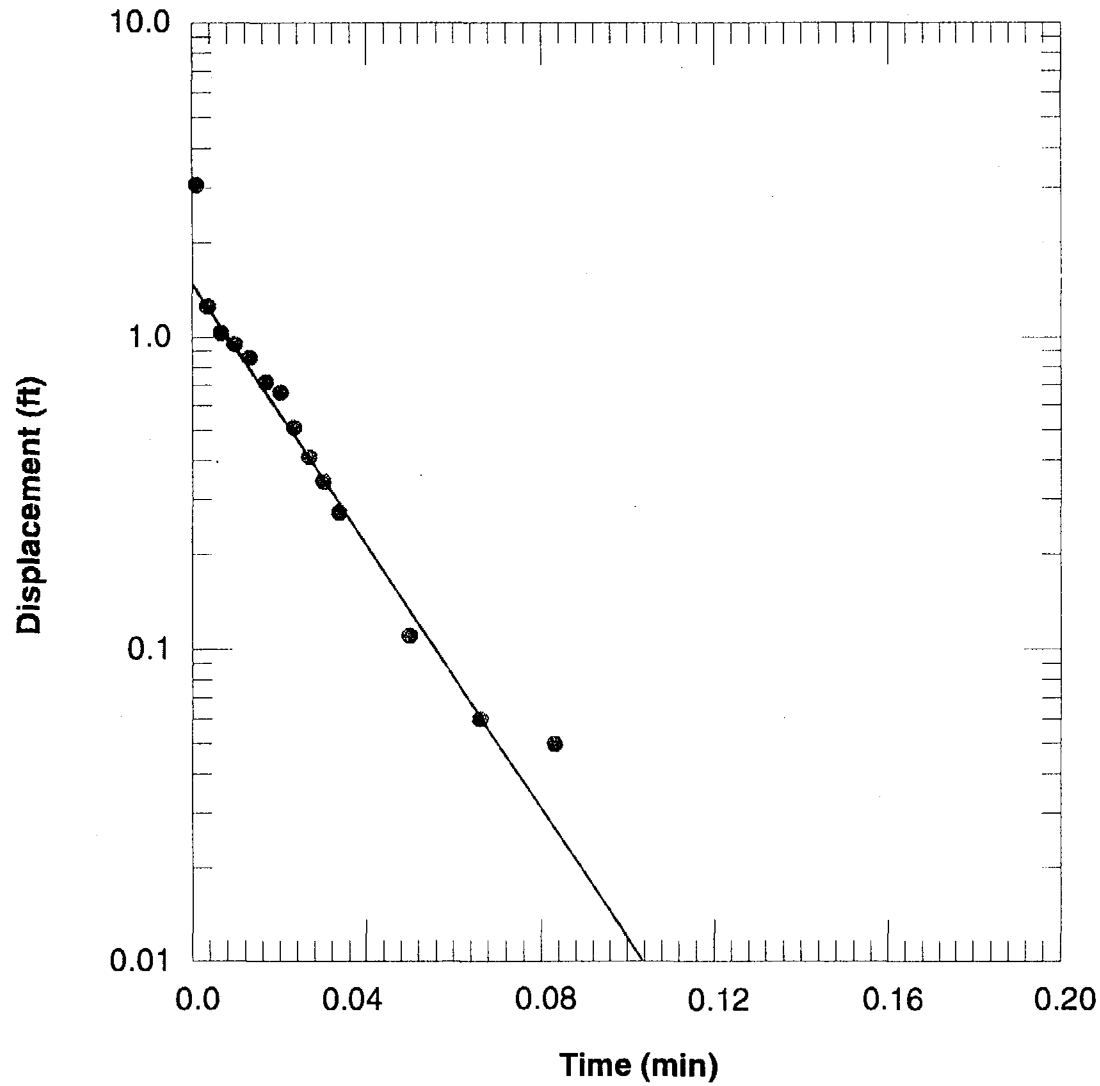
**TEST DATA**
HO = 3 ft
rc = 0.08333 ft
rw = 0.1667 ft
L = 15 ft
b = 38 ft
H = 38 ft

W03FH.CDR

E

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 03RH




**DATA SET**
wm03rhst.dat
10/17/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
03

**OBS. WELL**
03

**ESTIMATED PARAMETERS**
K = 0.04513 ft/min
y0 = 1.483 ft.

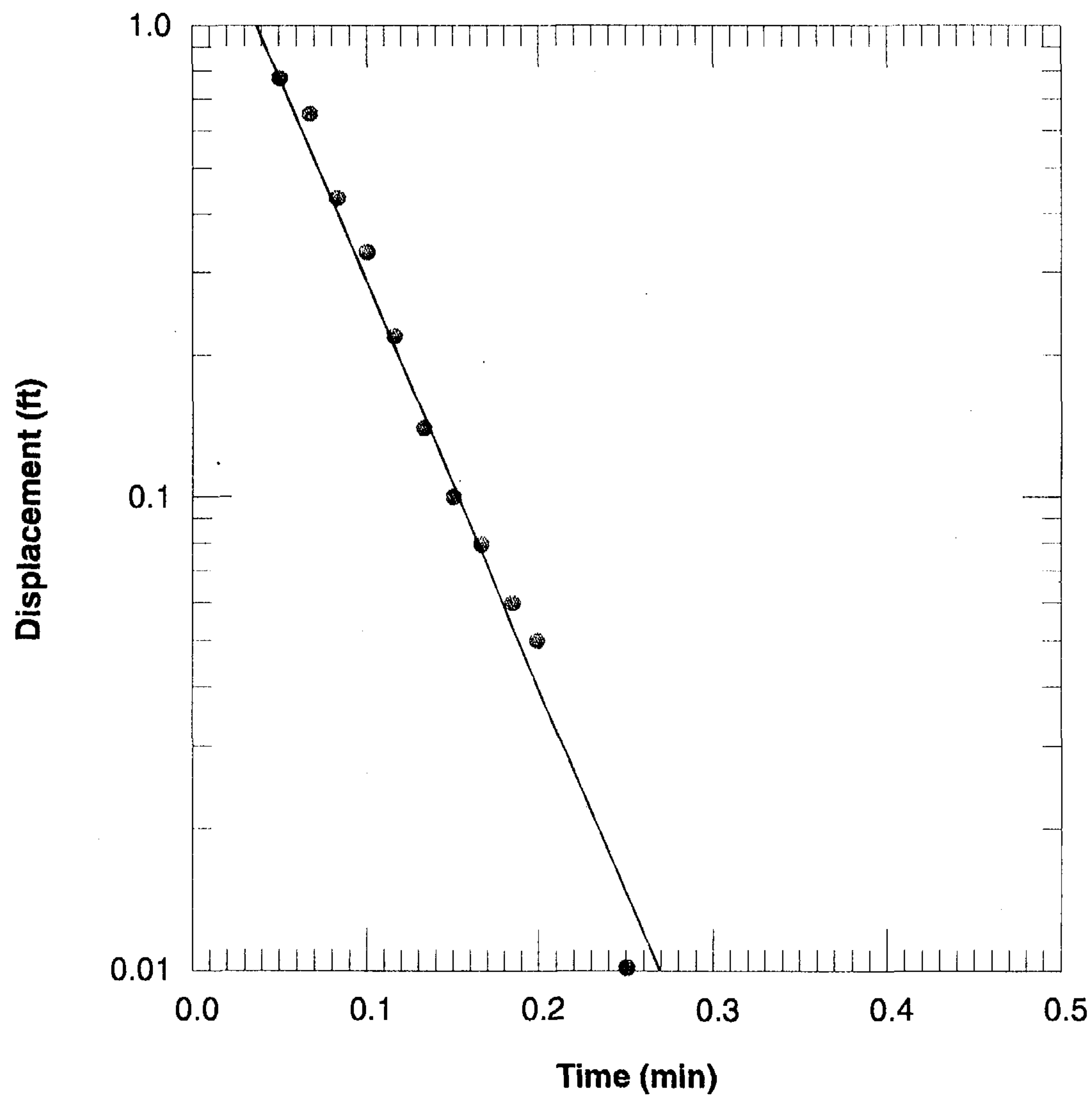
**TEST DATA**
HO = 3 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 15 ft
b = 38 ft
H = 38 ft

E

W03RH.CDR

| Research Project | Client: EPA/CDH/CMG |
|---|---|
| Project No: Wellington Mine | Location: Breckenridge, CO |

# French Gulch Mine Hydrology - Well 07FH




**DATA SET**
wm07fhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
07

**OBS. WELL**
07

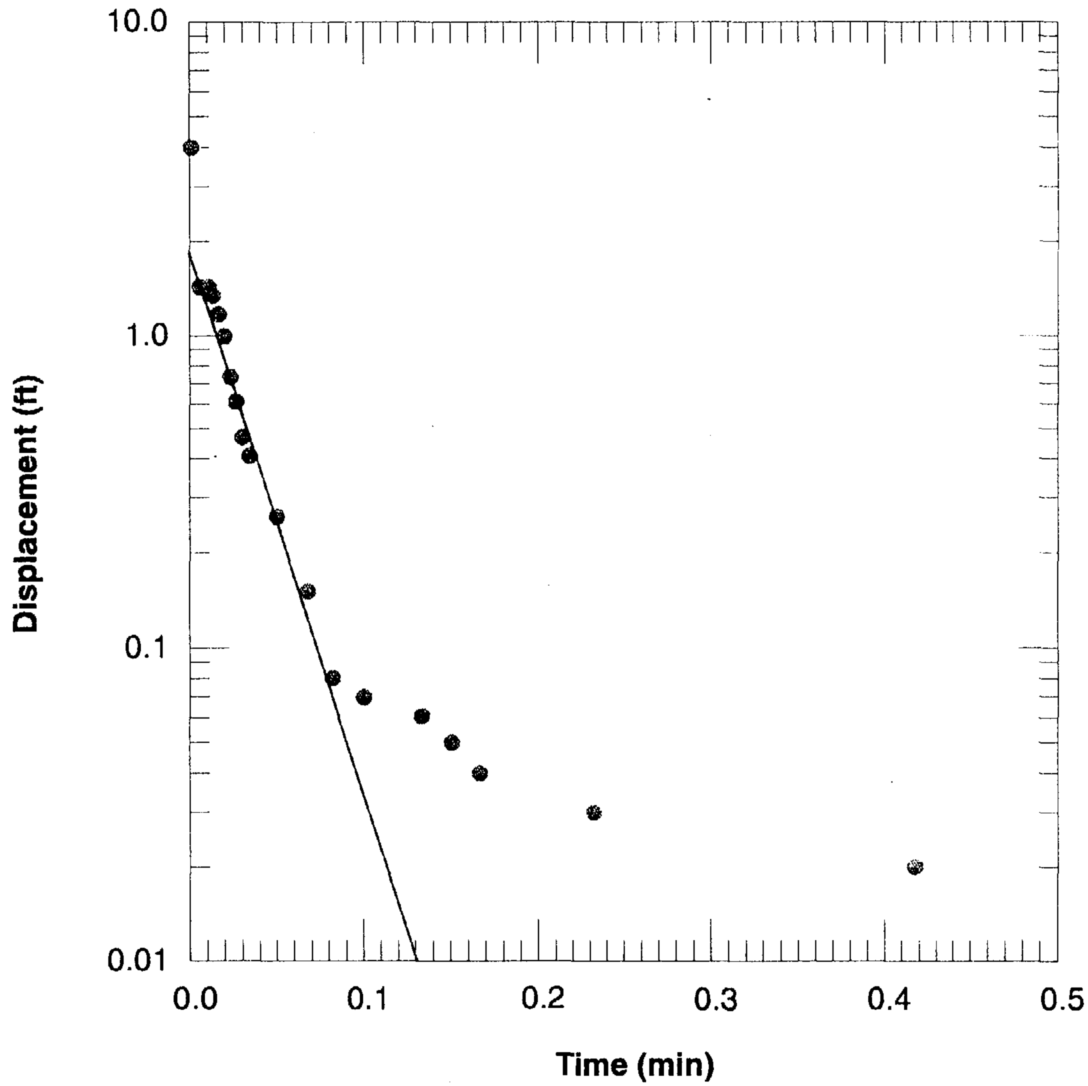
**ESTIMATED PARAMETERS**
K = 0.01833 ft/min
y0 = 2.103 ft.

**TEST DATA**
HO = 4 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 15 ft
b = 35 ft
H = 35 ft

07FH.CDR

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 07RH




**DATA SET**
wm07rhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
07

**OBS. WELL**
07

**ESTIMATED PARAMETERS**
K = 0.03678 ft/min
y0 = 1.847 ft.

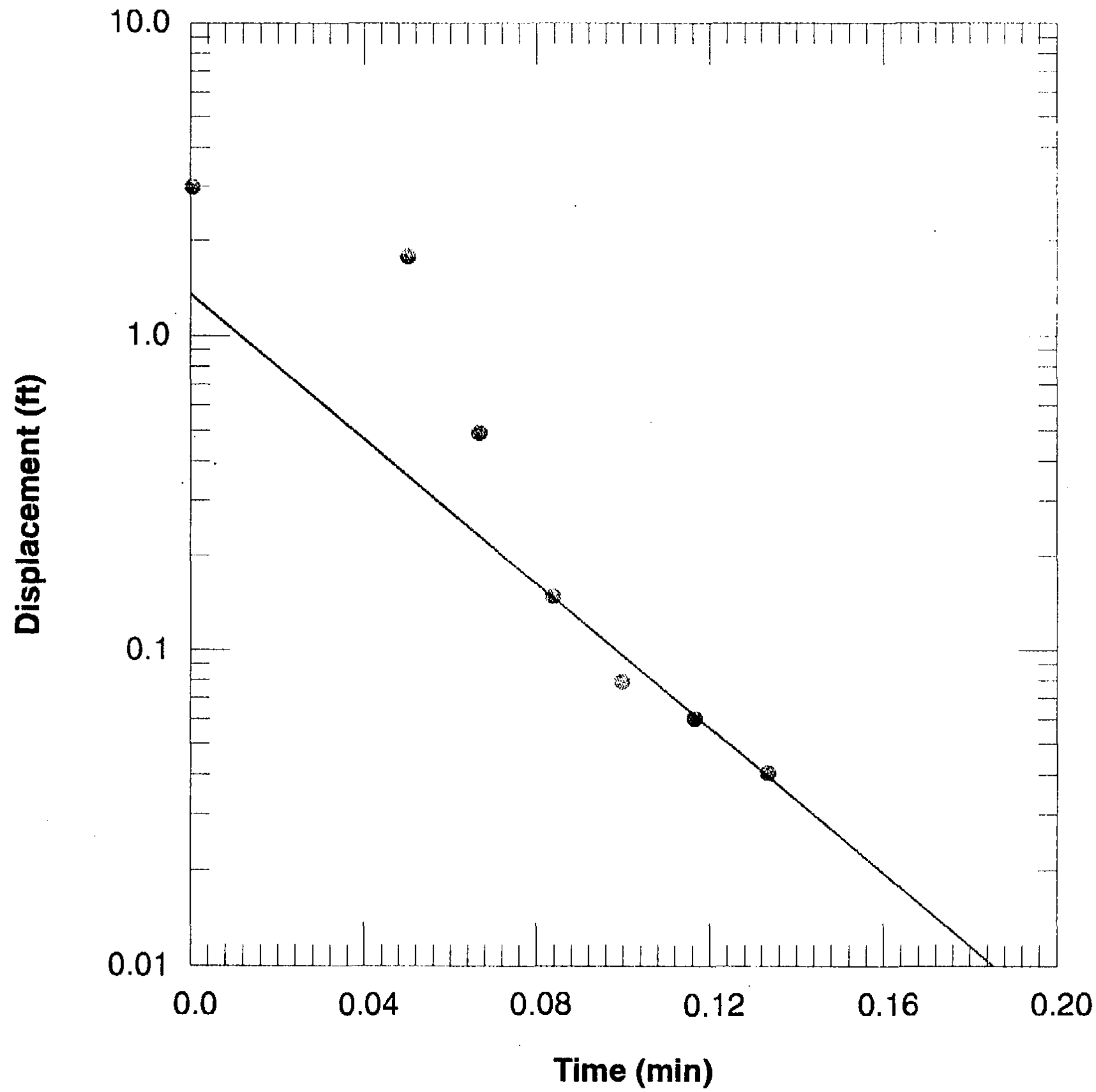
**TEST DATA**
HO = 4 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 15 ft
b = 35 ft
H = 35 ft

07RH.CDR

E

| | |
|---|---|
| **Research Project** | Client: **EPA/CDH/CMG** |
| Project No: **Wellington Mine** | Location: **Breckenridge, CO** |

# French Gulch Mine Hydrology - Well 08FH




**DATA SET**
wm08fhst.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
08

**OBS. WELL**
08

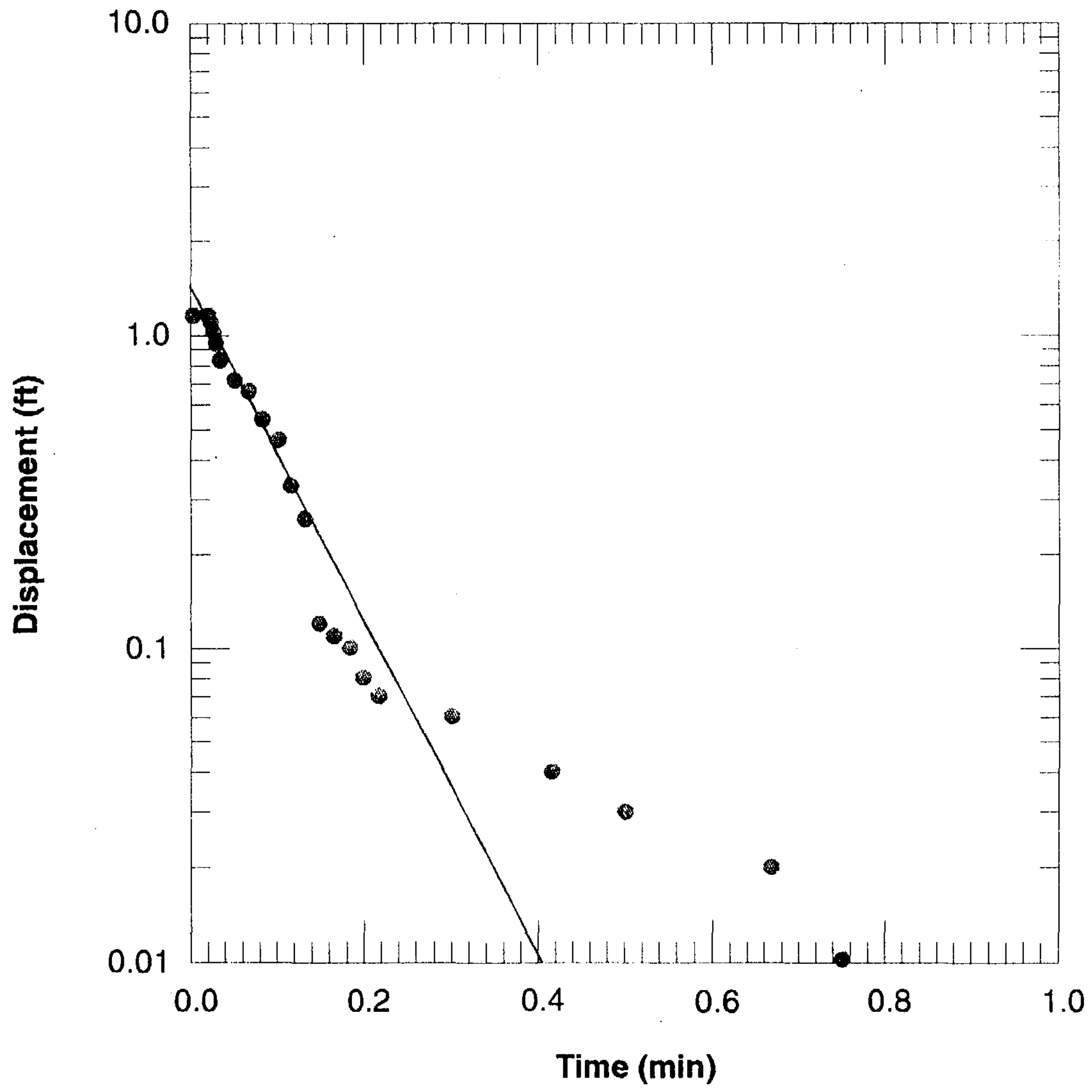
**ESTIMATED PARAMETERS**
K = 0.02781 ft/min
y0 = 1.354 ft.

**TEST DATA**
HO = 3 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 13 ft
b = 33 ft
H = 33 ft

08FH.CDR

| Research Project | Client: EPA/CDH/CMG |
| --- | --- |
| Project No: Wellington Mine | Location: Breckenridge, CO |

# French Gulch Mine Hydrology - Well 08RH




**DATA SET**
wm08rhsy.dat
10/14/94

**AQUIFER TYPE**
Unconfined

**SOLUTION METHOD**
Bouwer-Rice

**TEST DATA**
10/12/94

**TEST WELL**
08

**OBS. WELL**
08

**ESTIMATED PARAMETERS**
K = 0.01289 ft/min
y0 = 1.442 ft.

**TEST DATA**
HO = 1.15 ft
rc = 0.0833 ft
rw = 0.1667 ft
L = 13 ft
b = 33 ft
H = 33 ft

08RH.CDR

# APPENDIX
# F

## CONSTANT DISCHARGE TEST DATA & PLOTS

| | |
|---|---|
| F-1 | SURVEY NOTES FOR OBSERVATION WELLS |
| F-2 | STATIC WATER LEVELS ALLUVIAL PUMP TEST |
| F-3 | STATIC WATER LEVELS SHALE PUMP TEST |
| F-4 | DRAWDOWN DATA ALLUVIAL PUMP TEST (WELLS NOS. 1,5,18,16,17,4,8,13,& 3 MINE RELIEF) |
| F-5 | DRAWDOWN DATA SHALE PUMP TEST (WELLS NOS. 16,17,1,5,8,13,18, & 3 MINE RELIEF) |
| F-6 | RECOVERY DATA ALLUVIAL PUMP TEST (WELLS NOS. 5,1,4,8,13,16,17,18,& 3 MINE RELIEF) |
| F-7 | RECOVERY DATA SHALE PUMP TEST (WELLS NOS. 1,4,5,8,13,17,18,& 3 MINE RELIEF) |

SURVEY NOTES FOR PUMP TEST

| STA | FS | BRNG | DIST |
|---|---|---|---|
| #13 | RELIEFWELL | 256° | 32 ft. |
| #18 | #1 | 203° | 25' |
| #18 | #17 | 200° | 35.5' |
| #18 | #16 | 199° | 51' |
| #18 | #5 | 227° | ND |
| #18 | #4 | 191° | ND |
| #18 | #8 | 140° | ND |
| #18 | #13 | 60° | ND |
| | | | |
| #17 | RELIEFWELL | 332° | 31.5' |
| #17 | #1 | 355° | 14' |
| #17 | #18 | 20° | 35.5 |
| #17 | #16 | 190° | 16.5 |
| #17 | #5 | 230° | |
| #17 | #4 | 182° | 72' |
| #17 | #8 | | |
| #17 | #13 | | |

$\frac{40}{40}$ 80 20 mw

F-1

American Geological Services, Inc.
13701 West Jewell Ave., Suite 263
Lakewood, CO 80228
Tel.: (303) 988-1845

# WELL FLUID LEVEL DATA FORM

Project Name: FRENCH GULCH | Project Number:

Date: NOV. 1, 1994 | Recorded By: Water depth from surface | Unit of Measurement: FEET

| Well No. | Time | Water Depth from casing | Water Depth from ~~surface~~ casing | Product Depth from casing | Measuring Instrument | Notes |
|---|---|---|---|---|---|---|
| #18 | 0824 | *14.21 | 1455/14.10 | 11.66 | | -2.55 to GS |
| #17 | 0810 | 12.76 | 12.53 | 11.41 | | -1.35' to GS |
| #16 | 0812 | 12.05 | 12.12 | 11.2 | | -0.85' to GS |
| #3 MINE SHAFT | 0808 | 11.96 | 1443/12.06 | 10.96 | | -1.0' to ground surface |
| #1 | 0805 | 11.51 | 1442/11.62 | 10.66 | | -0.85' to ground surface |
| #4 | 0829 | 11.63 | 1443/11.63 | | | -1.20 to GS |
| #5 | 0817 | 6.48 | 1447/6.53 | 6.08 | | -0.4 to GS |
| #13 | 0824 | 32.22 | 1455/32.22 | | | -2.0 to GS |
| #8 | 0820 | 13.60' | 1450/13.59 | | | -1.8 to GS |
| | | | | | | |

Additional Comments:

* #18 Pom used is 2.50" .25' above Top of casing due to well head assembly. -2.55 ft from Top of casing to GS

14.875
13.5
.925

13.21
2.55
10.66

14.210
.25
13.96

1.350
.25
1.105

F-2

American Geological Services, Inc.
13701 West Jewell Ave., Suite 263
Lakewood, CO 80228
Tel.: (303) 988-1845

# WELL FLUID LEVEL DATA FORM

START PUMP @ 2GPM @ 10:00

Project Name: FRENCH GULCH

Project Number:

Date: NOV. 3, 1994

Recorded By:

Unit of Measurement: FEET

| Well No. | Time | Water Depth from casing | Water Depth from surface | Product Depth from casing | Measuring Instrument | Notes |
|---|---|---|---|---|---|---|
| #18 | | 14.~~21~~ ← 14.21 | | | | |
| #17 | | 12.94 | | | | |
| #16 | | 12.23 | | | | |
| #3 BIKESHOP | | 12.16 | | | | |
| #1 | | 11.72 | | | | |
| * #4 | 9:47 | 13'7 inches | | | | |
| #5 | 9:49 | 6.70 | | | | |
| #13 | 9:42 | 32.35 | | | | |
| #8 | 9:44 | 13.85 | | | | |
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Additional Comments:

* NOTE +1 FOR [illegible] CASING.
CORRECTED = 12'7"

PUMP TEST START @ 10:00:24 AM 11/3/94

F-3